COIGNET-BETON

AND

OTHER ARTIFICIAL STONE.

GILLMORE.

comprising such works as, from their rarity or value, should not be lent out, all unbound periodicals, and such text books as ought to be found in a library of reference, except when required by Committees of the Institute, or by Members or holders of second class stock, who have obtained the sanction of the Committee. The second class shall include those books intended for circulation.

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A PRACTICAL TREATISE ON COIGNET-BÉTON AND OTHER ARTIFICIAL STONE.

By Q. A. GILLMORE,

MAJOR CORPS OF ENGINEERS, BREVET MAJOR-GENERAL, U. S. A.

NEW YORK:

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1871.

NOTE.

THE professional paper, entitled "Report on Béton Aggloméré," which forms the leading feature, and indeed furnishes the basis of this small treatise, embraces all the nine plates as given by their titles, and that portion of the text preceding paragraph 132.

In preparing this edition for private circulation, descriptions of four other varieties of artificial stone, all more or less prominently before the public and therefore demanding notice, have been added, and the original index has been replaced by another covering the entire work, as thus modified and enlarged.

Q. A. G.

NEW YORK, *July*, 1871.

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PROFESSIONAL PAPERS, CORPS OF ENGINEERS, U. S. ARMY.
No. 19.

REPORT

ON

BÉTON AGGLOMÉRÉ;

OR,

COIGNET-BÉTON

AND

THE MATERIALS OF WHICH IT IS MADE,

BY

Q. A. GILLMORE,
MAJOR CORPS OF ENGINEERS, BREVET MAJOR GENERAL U. S. A.

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THE CORPS OF ENGINEERS

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HEADQUARTERS CORPS OF ENGINEERS.

1871.

LIST OF PLATES.

BÉTON AGGLOMÉRÉ.

MORTAR.

1. Calcareous mortar is compounded of one or more of the varieties of common lime, hydraulic lime, or hydraulic cement—natural or artificial—mixed with sand and water into a plastic condition.

The degree of strength and hardness, and consequently the durability, attained by mortar in setting, is dependent on the quality of the lime or cement employed, the kind and quantity of sand, the method and degree of manipulation, and the position, with respect to moisture or dryness, in which it is subsequently placed.

A mortar, of which the matrix is common lime only, will never harden under water, or to any considerable extent if kept in damp places, excluded from the air. A condition of constant humidity, on the contrary, is favorable to the induration of all hydraulic mortars.

CONCRETE OR BÉTON.

2. These terms, by no means originally synonymous, have become almost strictly so by usage. As generally received and understood in modern practice, they apply to any mixture of mortar, generally hydraulic, with coarse materials, such as gravel, pebbles, shells, or fragments of tile, brick, or stone. Two or more of these coarse ingredients, or all of them, may be mixed together.

The matrix of béton was formerly understood to possess hydraulic energy, while that of concrete, being derived from common lime, did not. A concrete, destitute of hydraulic energy, is seldom used in works of importance at the present day.

As lime, or cement paste, or a combination of the two, is the cementing substance or matrix in mortar, so mortar itself occupies a similar relation to concrete or béton. The proportions of the ingredients, in either case, should be determined on the principle that the *volume of matrix should*

always be somewhat in excess of the volume of voids in the materials to be united, the excess being added as a precaution against imperfect manipulation.

BÉTON AGGLOMÉRÉ.

3. This name is given to a béton of very superior quality, or, more properly speaking, an artificial stone, of great strength and hardness, which has resulted from the experiments and researches, extending through many years, of M. François Coignet, of Paris.

The essential conditions which must be carefully observed in making this béton are as follows:

First. Only materials of the first excellence of their kind, whether common or hydraulic lime, or hydraulic cement, can be used for the matrix.

Second. The quantity of water must not exceed what is barely sufficient to convert the matrix into a stiff, viscous paste.

Third. The matrix must be incorporated with the solid ingredients by a thorough and prolonged mixing or trituration, producing an artificial stone paste, decidedly incoherent in character until compacted by pressure, in which every grain of sand and gravel is completely coated with a thin film of the paste. There must be no excess of paste when the matrix is common lime alone. With hydraulic lime this precaution is less important, and with good cement it is unnecessary.

Fourth. The béton or artificial stone is formed by thoroughly ramming the stone paste, in thin, successive layers, with iron-shod rammers.

MATERIALS SUITABLE FOR BÉTON AGGLOMÉRÉ.

The materials employed in making this béton are as follows:

4. **Sand.**—The sand should be as clean as that ordinarily required for mortar, for stone or brick masonry of good quality. Sand containing 5 or 6 per cent. of clay may be used without washing, for common work, by proportionally increasing the amount of matrix. Either fine or coarse sand will answer, or, preferably, a mixture of both, containing gravel as large as a small pea, and even a small proportion of pebbles as large as a hazel nut. There is an advantage in mixing several sizes together, in such proportion as shall reduce the volume of voids to a minimum. Coarse sand makes a harder and stronger béton than fine sand. The extremes to be avoided are a too

minute subdivision and weakening of the matrix, by the use of fine sand only, on the one hand, and an undue enlargement of the volume of voids, by the exclusive use of coarse sand, on the other.

The silicious sands are considered the best, though all kinds are employed. When special results are desired in the way of strength, texture, or color, the sand should be selected accordingly.

5. **Common or fat lime.**—The lime should be air-slaked, or, better still, it may be slaked by aspersion with the minimum quantity of water that will reduce it to an impalpable powder. It should be passed through a fine wire screen to exclude all lumps, and used within a day or two after slaking, or else kept in boxes or barrels protected from the atmosphere.

It is scarcely practicable, under ordinary circumstances, to employ fat lime alone as the matrix of béton aggloméré, particularly in monolithic constructions, in consequence of its tardy induration. Even when used in combination with hydraulic lime or cement it acts as a diluent.

M. Coignet claims, with great confidence, if not with correct judgment, that good béton can be made with sand and fat lime alone, but it is not so employed in his artificial stone manufactory at St. Denis, and it is believed that all the works executed in béton by the company of which he is the head have contained hydraulic lime or cement. Attempts to make béton of even average quality, without good hydraulic ingredients, have failed in the United States; and it is extremely doubtful whether any characteristic excellence can be attained, after the lapse of weeks or even months, by a mixture of this character.

When a matrix of fat lime alone must be employed for want of a better material, the manipulation should be conducted with watchful care. The quantity of water must be limited strictly to what is necessary to convert the lime powder into a stiff paste; and of this paste only enough must be used to cover each grain of sand and gravel with a thin, impalpable coating. The other conditions of prolonged trituration and thorough ramming, already referred to, are common to all varieties of this béton.

6. **Hydraulic lime.**—The most suitable limes are, like those of Theil, Seilley, and other localities in France, derived from the argillaceous limestones, in contradistinction to the magnesian or argillo-magnesian varieties. These limestones contain

before burning from 15 to 25 per cent.—generally less than 20 per cent.—of clay. After burning, the lime is slaked to powder by aspersion with water, and sifted to exclude unslaked lumps.

Hydraulic lime cannot be considered an essential ingredient of béton aggloméré, except in comparison with common lime. It may be altogether replaced by good hydraulic cement, or it may be used alone, or mixed with common lime, to the entire exclusion of cement. A stiff paste of this lime should set in the air in from ten to fifteen hours, and sustain a wire point one-twenty-fourth of an inch in diameter, loaded with one pound, in eighteen to twenty-four hours. Its energy, and therefore its value, varies directly with the amount of clay which it contains, which generally will not exceed 20 per cent. before burning, although it may reach 25 per cent. Beyond this point the burnt stone can seldom be reduced by slaking and becomes a cement.

No hydraulic lime of this variety has ever been manufactured in the United States. It is not known that stone suitable for it exists here.

7. Among hydraulic limes, those of Theil and Seilley, France, may be assumed as of fair average quality. They have been extensively used in the works executed in béton aggloméré, under the supervision of M. Coignet.

Theil lime alone supplied the matrix of the bétons used in the construction of the light-house and jetties at Port Said, Egypt. Its light color renders it suitable for statuary and works of ornamentation, in which the delicate shades of gray and drab are desirable.

8. Analysis of raw Theil limesone:

Carbonate of lime	81.36
Carbonate of magnesia	1.00
Clay	14.90
Oxide of iron	1.70
Water and bitumen	1.10

9. The Theil hydraulic lime, slaked to an impalpable powder, weighs $71\frac{1}{4}$ pounds to the struck United States bushel, when poured into the measure loosely; and $84\frac{1}{4}$ pounds, if compacted by shaking and jarring. Under the same condition, the Seilley lime weighs 54 pounds and 66 pounds, respectively. These weights were carefully determined from average samples taken from cargoes received in New York.

10. **Portland Cement.**—The heavy slow-setting Portland cements, natural or artificial, are the only ones suitable for béton

aggloméré. They are manufactured extensively throughout Europe. Among the most noted works are those at Boulogne-Sur-Mer and Seilley, in France; at Bieberich, Limburg, and Stettin, in Germany; at Dresden, in Saxony, and several in the neighborhood of London and Liverpool, England.

This cement is produced by burning, with a heat of great intensity and duration, argillaceous limestones, containing from 20 to 22 per cent. of clay, or an artificial mixture of carbonate of lime and clay in similar proportions, and then reducing the product to fine powder between millstones. In this condition its weight should not fall short of 101 pounds and will seldom exceed 128 pounds to the bushel, poured in loosely and struck, without being shaken down or compacted. Between these limits additional weight may always be conferred in the burning, by augmenting the intensity and duration of the heat; and both the tensile strength, and the time required to *set*, increase directly with the weight. For example, a Portland cement weighing 100 pounds to the United States bushel, that will set in half an hour, and sustain when seven days old a tensile strain of 200 pounds on a sectional area of one square inch, would have its time for setting increased to four or five hours, and its tensile strength to about 400 pounds, if burnt to weigh 124 pounds to the bushel. An increase in weight of 24 pounds to the bushel nearly doubles the ultimate tensile strength of Portland cement.

When the matrix of béton aggloméré is Portland cement alone, it is customary to prolong the process of trituration, in order to retard the set; or, if more convenient, the mixture may be passed through the mill twice or even three times, with an interval of an hour or more between each mixing. This course is specially desirable when the cement weighs less than 100 pounds to the bushel, and is correspondingly quick-setting.

TESTS FOR PORTLAND CEMENT.

11. **English test.**—English engineers generally require that the cement shall be ground so fine that at least 90 per cent. of it shall pass a No. 30 wire sieve, of 36 wires to the lineal inch, and shall weigh not less than 106 pounds to the struck bushel, when loosely poured into the measure. When made into a stiff paste without sand, it should be capable of sustaining without rupture, a tensile strain of 400 pounds on a sectional area $1\frac{1}{2}$ inch square, or $2\frac{1}{4}$ square inches, (equal to 178 pounds to the sectional square inch,) seven days after being moulded, the sample being immersed six of these days in fresh water.

In some cases a weight per bushel of 110 pounds, and a tensile strength, at the age named, of 222 pounds per square inch, are required.

12. **French test.**—The tests applied by French engineers are not difficult to fulfil, and are considerably below what a good Portland cement will sustain. The cement must be ground to a fine powder, so that not more than 10 per cent. will fail to pass a No. 35 wire cloth of 47 meshes to the lineal inch, and weigh when loosely poured into the measure not less than 1,230 grammes to the litre, which is equal to about 97 pounds to the United States bushel.

The test of strength is applied to a stiff mortar composed of what is equivalent to about $3\frac{1}{2}$ quarts of dry sand and $10\frac{1}{2}$ quarts of cement powder, which, being mixed with fresh water and formed in a suitable mould, is at once immersed in water. At the end of five days it should sustain a tensile strain of 167 pounds on a section of 2.48 square inches, equal to $67\frac{1}{2}$ pounds to the sectional area of 1 square inch; and at the end of 45 days, immersed in sea-water, the tensile strength to the square inch must not fall short of 142 pounds.

The cement is required to be slow-setting. Should a stiff paste without sand sustain, in less than two hours, the point of a square needle, measuring $1\frac{1}{2}$ millimetres (about $\frac{59}{1000}$ of an inch) on the side, loaded to $3\frac{14}{100}$ pounds, it is rejected. It is, however, required to support, without the least depression, the the same loaded needle at the expiration of ten hours. Samples from a cargo of Boulogne Portland cement, received in New York in July, 1870, weighed 97 pounds to the United States bushel when poured loosely into the measure, and 127 pounds when well compacted by shaking.

13. **German cement.**—The standard Portland cements of Germany generally range in weight, when poured loosely into the measure, from 90 to 100 pounds to the struck United States bushel. A sample from a lot of Stettin cement weighed 89 pounds to the bushel, loose, and $116\frac{1}{2}$ pounds when well shaken. Another sample weighed 95 and 122 pounds respectively, similarly treated.

14. Composition of Portland cement, (from analyses:)

Boulogne Portland cement, (natural.)

Lime	65.13
Magnesia	.58
Silica	20.42
Alumina and small quantity of oxide of iron	13.87
Sulphate of lime	a trace.

London Portland cement, (artificial.)

From Messrs. J. B. White & Brothers.

Lime	68.11
Silica	20.67
Alumina	10.43
Oxide of iron	.87

MATERIALS NOT SUITABLE FOR BÉTON AGGLOMÉRÉ.

15. As a rule, all hydraulic cements produced at a low heat, whether derived from argillaceous or argillo-magnesian limestones, are light in weight and quick-setting, and never attain, when made into mortar or béton, more than 30 to 33 per cent. of the strength and hardness of Portland cement placed in similar circumstances. They are also greatly inferior to good hydraulic lime. This is true of all cements made at a low heat, including even those derived from limestones, that might, with proper burning, have yielded Portland cement. The celebrated Roman cement, the twice-kilned artificial cements, the quick-setting French cement, like that of Vassy, and all the hydraulic cements manufactured at the present day in the United States, belong to this category. They are incapable, under any known method or degree of manipulation, of producing a matrix suitable for béton aggloméré of good quality. These kinds of cement generally weigh, among the different varieties, from 65 to 80 pounds to the United States bushel, poured in loosely, and from 80 to 93 pounds if compacted by shaking and jarring the measure.

The weight of Rosendale cement per bushel is 67 pounds when loose, and 92 pounds when well shaken down.

16. Analyses of light, quick-setting cements:

Rosendale cement stone, (New York.)		*Cumberland cement stone, (Maryland.)*	
Carbonate of lime	46.00	Carbonate of lime	41.80
Silica, clay, and insoluble silicates	27.70	Silica, clay, and insoluble silicates	24.74
Carbonate of magnesia	17.76	Magnesia	4.10
Alumina	2.34	Alumina	16.74
Peroxide of iron	1.26	Peroxide of iron	6.30
Sulphuric acid	.26	Soda	4.64
Chlorides of potassium and sodium	4.02	Potash	1.54
Hygrometric water	.22	Sulphuric acid	2.22
Loss	.44	Hygrometric water	.60
	100.00	Gain, (2.68)	102.68

Vassy cement stone, (France.)		*Balcony Falls stone, (Virginia.)*	
Carbonate of lime	63.8	Lime	17.38
Silica	14.0	Silica	34.22
Alumina	5.7	Alumina	7.80
Carbonate of iron	11.6	Magnesia	9.51
Carbonate of magnesia	1.5	Carbonic acid	30.40
Water and loss	3.4	Water and loss	.69
	100.00		100.00

For analyses of several other cements of this class, see Gillmore on Limes, &c., page 125.

THE INDURATION OF MORTARS.

17. The setting or hardening of mortars, except so far as it is due in some degree to the absorption of carbonic acid from the atmosphere, is a species of crystallization induced when water is added to the compounds found in the kiln by the agency of heat.

Mortars of common lime harden by the absorption of carbonic acid from the atmosphere, by which a sub-carbonate of lime is formed. The lime never takes up its full equivalent of carbonic acid.

If the limestone be silicious, the calcination produces silicate of lime.

$$Si\ O_3\ 3\ Ca\ O,$$

which becomes hydrated by combining with six equivalents of water, producing hydrosilicate of lime,

$$Si\ O_3\ 3Ca\ O+6\ HO.$$

If the carbonate of lime be in excess in the stone, the burnt product will contain both silicate of lime, and quicklime, or protoxide of calcium.

It will slake to powder by the suffusion of water, if the quicklime be present in sufficient quantity, producing a species of hydraulic lime, of which the hydraulic energy will depend on the amount of silicate produced during the calcination.

If the limestone be argillaceous—that is, if it contain alumina as well as silica—a calcination at a *low heat* produces both silicate and aluminate of lime. The latter becomes hydrated by taking six equivalents of water, and is then represented by the formula

$$Al\ O_3\ 3\ Ca\ O+6\ HO.$$

If the silica and alumina be present in the form of homogeneous clay, and in suitable quantity, say less than 20 per cent., the burnt stone will slake, yielding hydraulic lime resembling more or less those of Seilley and Theil, France. If more than 20 per cent. of clay be present, the lime will be so little in excess that the burnt stone may not slake, but must be reduced to powder by grinding. The result, if burnt at a *low heat*, is light, quick-setting cement, like the Roman.

If this stone be burnt at a *high heat*, the reactions in the kiln are somewhat more complicated, particularly when the point of incipient vitrification is reached, a variable point, dependent in a great measure on the fluxes present in the stone. The compounds formed under these conditions, however, require but

three equivalents of water for their hydration, their formulas being

$$Al_2\ O_3\ 3\ Ca\ O+3\ HO,$$
$$Si\ O_3\ 3\ Ca\ O+3\ HO.$$

Herein lies the probable cause, in a great measure, of the superior strength and hardness attained by Portland cement over the quick-setting varieties burnt at a low heat, in which the compounds take *six* equivalents of water to form hydrates.

Magnesia plays an important part in the setting of mortars derived from the argillo-magnesian limestones, such as those which furnish the Rosendale cements.

The magnesia, like the lime, appears in the form of the carbonate, ($Mg\ O\ C\ O_2$.) During the calcination the carbonic acid is driven off, leaving protoxide of magnesia, ($Mg\ O$,) which comports itself like lime, in the presence of silica and alumina, by forming silicate of magnesia and aluminate of magnesia.

$$Si\ O_3\ 3Mg\ O,$$
$$Al_2\ O_3\ 3\ Mg\ O.$$

These compounds become hydrated in the presence of water, and are pronounced by both Vicat and Chatoney to furnish gangs which resist the dissolving action of sea water better than the silicate and aluminate of lime. This statement is doubtless correct, for we know that all of those compounds, whether in air or water, absorbs carbonic acid, and pass to the condition of sub-carbonates; and that the carbonite of lime is more soluble in water holding carbonic acid and certain organic acids of the soil, in solution, than the carbonate of magnesia.

Hence cements derived from argillo-magnesian limestones are durable for constructions in the sea, unless other ingredients introduce adverse conditions.

THE FABRICATION OF BÉTONS AGGLOMÉRÉS.

18. Experience has repeatedly demonstrated, and they have become well recognized facts, that in order to obtain uniformly good béton or artificial stone, with sand, and either hydraulic lime or Portland cement, or both, it is necessary—

First. To regulate, in a systematic manner, the amount of water employed in the manufacture thereof.

Second. To obtain, with a minimum quantity of water, the cementing material or matrix in a state of plastic or viscous paste.

Third. To cause each grain of sand or gravel to be entirely lubricated with a thin film or coating of this paste; and

Fourth. To bring each and every grain into close and intimate contact with those which surround it.

It is also equally true, that the best results possible to be produced from any given materials will be attained when the above-named conditions are enforced.

TREATMENT OF THE MATRIX.

19. It is impossible to produce a cementing material, of suitable quality for béton aggloméré, by the ordinary methods and machinery used for making mortars; for if we take the powder of hydraulic lime or Portland cement, and add the quantity of water necessary to convert it into a paste by the usual treatment, it will usually contain so much moisture, even after being incorporated with the sand, that it cannot be compacted by ramming, but will yield under the repeated blows of the rammer like jelly. If the quantity of water be reduced to that point which would render the mixture, with the usual treatment, susceptible of being thoroughly compacted by rammers, much of the cementing substance will remain more or less inert, and will perform but indifferently well the functions of a matrix.

To prepare the matrix, there is taken of the hydraulic lime or cement powder, say one hundred parts, by measure, and of water from thirty to thirty-five or forty parts, which should be the smallest amount that will accomplish the object in view. These are introduced together into a suitable mill, acting upon the materials by both compression and friction, and are subjected to a thorough and prolonged trituration, until the result is a plastic, viscous, and sticky paste, of a peculiar character, in both its physical appearance and the manner in which it comports itself under the subsequent treatment with rammers. There would appear to be no mystery in this part of the process, yet the excellence of the béton aggloméré is greatly dependent on its proper execution.

If too much water be used, the mixture cannot be suitably rammed; if too little, it will be deficient in strength.

TREATMENT OF THE SAND.

20. The sand should be deprived of surplus moisture, although it is not necessary that it be absolutely dry. A uniform state of moisture or dryness should be aimed at, in order that the

proper quantity of water may be added with certainty. With regard to the selection of the sand, nothing need be added to what has been said in paragraph 4.

TRITURATION.

21. The matrix in paste, and the sand, having been mixed together in the desired proportions, (given hereafter,) are then introduced into a powerful mill, and subjected to a thorough and energetic trituration until, without the addition of more water, the paste presents the desired degree of homogeneity and plasticity.

When, for any special purpose, it is desired to introduce into the mixture a quantity of Portland cement, in order to increase the hardness or the rapidity of induration, it had better be added during the process of trituration, mixed with the requisite increment of water, so that after proper mixing the whole material will present the appearance of a short paste, or pasty powder, which is quite characteristic of this process of manipulation.

In ordinary practice, when sand and hydraulic lime only are employed, it will be found to answer very well to mix the two together dry, with shovels, and then spread them out on the floor and sprinkle them with the requisite minimum amount of water. The dampened mixture is then shovelled into the mill and triturated, as already described.

When a portion of Portland cement is used, it may also be incorporated with the other ingredients before the water is added, or introduced into the mixture in the mill, as may be preferred.

When Portland alone is used for the matrix, the process is the same as when lime alone is used, except that the trituration should be more prolonged, especially if the cement be rather light and quick-setting.

22. The market value of Portland cement per ton is generally not far from double that of good hydraulic lime. Having both equally at command, the following proportions are employed for divers purposes, according to circumstances and the quality of the materials:

Sand, by volume	6	5	4	5	5	4	4	5	5	5
Hydraulic lime in powder, by volume	1	1	1	1	1	1	1	1	1	1
Portland cement in powder, by volume	0	0	0	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{2}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$

It will rarely occur that the proportions given in the two columns on the right of the above table need be used. They are suitable for ornamented blocks, requiring removal and handling a day or two after being made.

23. It may sometimes happen that too much water has been introduced in the preparation of the paste. A proper corrective, in such case, is the introduction into the mill of a suitable quantity of each of the ingredients, mixed together dry in the required proportions.

By employing none but white sand and the lighter-colored varieties of lime and cement, a stone closely imitating white marble may be made, while, by the introduction of coloring matter into the paste, such as ochres, oxides, carbonates, &c., or fragments of natural stones, any variations in shade or texture may be produced, from the most delicate buff and drab, to the darkest grays and browns.

In some cases it may be found more convenient to measure the ingredients directly into the mill, alternating with the different materials, in regular order, using for the purpose measures of various sizes, corresponding with the required proportions.

When it is specially desirable to obtain stone of the maximum degree of strength and hardness, the paste may be returned a second or even a third time to the mill, but in all cases the mass must be brought to the characteristic state of incoherent pasty powder, or short paste.

AGGLOMERATION.

24. The materials, after being mixed to a state of pasty powder, have to be agglomerated in moulds, in order to become béton or artificial stone. In other words, the grains of sand and gravel, each coated all over with a thin film of the matrix—entirely exhausting the matrix thereby—have to be brought into close and intimate contact with each other. This is accomplished by ramming the paste in thin, successive layers, in a mould of the form and dimensions required for the stone, and made so as to be capable of sustaining heavy pressure from within, and of being taken apart at pleasure.

Into this mould, supposing it to be for a detached building block, and not for monolithic masonry, a quantity of the stone paste is thrown with a shovel, and spread out in a layer from $1\frac{1}{2}$ to 2 inches thick. It is then thoroughly compacted by the

repeated and systematic blows of an iron-shod rammer, until the stratum of material is reduced to about one-third its original thickness. When this is done, its surface is scratched or roughened up with an iron rake, in order to secure a perfect bond with the succeeding stratum, and more of the material is added and packed in the same manner. This process is continued until the mould is full. The upper surface is then struck with a straight-edge, and smoothed off with a trowel, after which the full mould may at once be turned over on a bed of sand, and the bottom, side, and end pieces removed. The block is then finished. If small, such as one man can handle, it may be safely removed after one day. Larger pieces, like sills, lintels, steps, platforms, &c., should be allowed a longer time to harden, in consequence of their greater weight.

In case of monolithic masonry, the moulds usually consist of a series of planks placed one above the other horizontally, and supported against exterior uprights, so arranged as to give the required form to the work under construction. These planks are raised up as the wall progresses, so that each day's work shall unite intimately with that of the previous day, producing a smooth and even surface, without joints, ridges, or marks of any kind.

25. A characteristic property of this stone paste, when properly mixed, is that it does not assume a jelly-like motion when rammed.

Its degree of moisture must be precisely such that the effect of each blow of the rammer shall be distinct, local, and permanent, without disturbing the contiguous material compacted by previous blows. If it be too moist, the mass will shake like wet clay, and if it be too dry, it will break up around the rammer like sand. In either case the materials cannot be compacted and agglomerated in that manner and to that degree which is characteristic of, and peculiar to, béton aggloméré.

26. In monolithic buildings of this béton, it is customary to construct all the flues, pipes, and other openings for heating and ventilating, and for conveying water, gas, and smoke, in the thickness of the wall, by using movable cores of the required size and form, around which the material is packed. As the work progresses the cores are moved up.

Ornamental work of simple design may be placed upon the exterior of the building, by attaching the moulds to the planking which gives form to the wall.

More elaborate designs, especially if they are of bold relief, like cornices, and hoods for windows and doors, had better be moulded in detached pieces some days in advance, and hoisted into position when required.

27. All kinds of masonry in thin walls, whether of brick, stone, common concrete, or béton aggloméré, are liable to crack from unequal settlement, or from the expansion and contraction due to ordinary changes of temperature. In houses, such cracks are more to be apprehended at the reëntering angles of the exterior walls, and at the junctions of the exterior and partition walls, than elsewhere. In concrete or béton masonry, such cracks may be prevented in a great measure, without inconvenience and at a nominal cost, by imbedding and incorporating in the work as it progresses, at the angles and junctions referred to, pieces of old scrap-iron of irregular shape, such as bolts, rings, hooks, clamps, wire, &c.

28. Any masonry of fair quality, constructed in large masses with special reference to inertia, whether to resist the thrusts of earthen embankments, the statical pressure of water, the force of the current in running streams, or for any other purpose, possesses a degree of ultimate strength much greater than the usual factor of safety would require, and largely in excess of any strain that it would ever have to sustain. This excess of strength, or rather the material which confers it, may be readily saved in works built of béton aggloméré, by leaving large hollows or voids in the heart of the wall, and filling them up with sand or heavy earth.

Even if the voids remain unfilled, a hollow wall is more stable than a solid one containing the same quantity of material, for the reason that the moments of the forces which confer stability are greater in the former than in the latter.

MACHINERY AND IMPLEMENTS.

29. All the machinery and appliances for making béton aggloméré are simple in character, and not liable to get out of order with use.

They comprise, besides the necessary shovels and measures for handling and apportioning the ingredients,

1. A machine for mixing the materials together.
2. The means for conveying it, after mixing, to the place where it is to be used.
3. Rammers for compacting the materials in the moulds.
4. Moulds of the required form.

30. **Mixing machine.**—The first requiste is a machine that shall thoroughly and uniformly mix the ingredients together. It has been found in practice that a combined pressing and rolling motion secures the best results.

31. *The ordinary upright pug mill*, modified in some of its details, answers this purpose. It is cylindrical in form, made of boiler iron, and has a vertical revolving shaft in the axis, armed with horizontal radial arms or knives, arranged spirally around it. Other horizontal arms are attached to the inner surface of the cylinder, projecting out between the revolving arms, so as to subdivide the materials and aid the mixing. Three or four of the revolving arms, near the lower end of the shaft, are made warped, or helicoidal, like the blades of a screw-propeller, to press down as well as stir the mixture; and below these, revolving near the floor or bottom of the mill, are three cycloidal arms, to force out the mixed materials at the side openings around the bottom, whence it is at once conveyed away for use. These openings are provided with cylindrical sliding gates, by means of which their area may be diminished, and the rapidity with which the material is expelled, retarded, whenever, for special purposes, a prolonged trituration is desirable.

As the béton, ready for use, is ejected at the bottom, the cylinder is kept full by new material introduced at the top, a measure of cement, lime and sand, incorporated dry, alternating with a proportionate measure of water.

In operating with mills of large capacity, there is an advantage in conveying up the materials with an elevator discharging its buckets into an inclined shoot leading into the mouth of the cylinder.

The requisite amount of water may be supplied by constant flow from a pipe. This amount must, however, be ascertained by trial, and will vary with the character and the proportions of the lime and cement used.

In conducting extensive operations the mill should be worked by steam-power.

32. *The Greyveldinger mortar mill* is believed to be fully equal, if not superior, to the pug mill. It is an Archimedean screw, revolving in a cylindrical trough. The dry ingredients of the béton, having first been roughly mixed with shovels, are introduced at one end of the screw with the requisite amount of water, and after an interval of fifteen or twenty seconds issue from the other end in a condition of thoroughly mixed béton. When used for making common mortar, the screw may occupy

a horizontal position, but for béton aggloméré it is better to have it set at an angle of about twenty-five degrees with the horizon, in order that the benefits of the trituration and pressure, developed in forcing the material up the inclined cylinder, may be secured. A convenient way of accomplishing this object is to mount the machine on wheels like a cart, as shown in Plate III.

A mortar mill of this kind, set horizontally, of suitable size to be driven by a half-horse-power engine, can make $38\frac{3}{10}$ cubic yards of mortar in ten hours, the force required to tend it being 8 common laborers, 1 foreman, and 1 engineer.

Estimating common labor at $1 70 per day, and the wages of engineer and foreman at $2 50 and $2, respectively, the cost of making mortar by this mill, including the coal, would be 48 cents per cubic yard. The more thorough and prolonged trituration required for béton aggloméré, and the additional power expended in forcing the mixture up the inclined cylinder, would augment the cost about 10 per cent.

33. **The malaxator.**—Many advantages are claimed for a mill designed by M. Coignet, recently introduced in France, and employed in mixing béton aggloméré for the works in and about Paris. It is called a malaxator, and consists of twin screws, having their helices interlocked, and turning and exerting their force in the same direction. This machine may be described as follows: (See Plate II.)

A is the frame of the machine, having at the upper end the cross-pieces B, upon which are mounted the gearings, and at the lower part the cross-piece c c′, upon which are fixed the rests or steps for the lower part of the helices to run in.

D are the cores of the helices, upon which are fastened either continuous or interrupted blades S S S, forming the thread of the helix. Continuous blades are more generally used.

K are wagon-wheels, mounted on an axle, which enable the machine to be transported thereon, and which, when the machine is in use, serve to maintain the malaxator at its proper inclination, (about twenty-five degrees.) The brace J is used to steady the malaxator.

M N *m* N′, gearings of any kind for giving motion to the helices, either by steam, horse-power, or hand-power; *q*, conical sleeves or stoppers, adjustable upon the shafts D, for regulating the exodus of the artificial stone paste, and by retarding the same, increasing the pressure and malaxation of the paste in the part Q′ of the machine.

Q, body of the malaxator, corresponding in shape and size to the helices.

P, receiving chamber, where the materials enter the malaxator.

T, sand hopper, with its adjustable register or gate *t*, and, when required, a sifting apparatus; *q′*, sliding gate, to allow of the drainage of the machine.

S′ S′, feeding screws, working in the lower part of the two hoppers R′ R′, the one for lime, the other for sand, or any other material or substance to be introduced into the artificial stone paste, and feeding the same to the chamber P; *r r′ r″ r‴*, pulleys, for chains or belts *g*, for transmitting the movement to the feeding screws S′ S′; *t′ t″*, spur-wheel and pinion, (changeable for others of different relative speed,) for regulating the exact amount of the two substances in the hoppers R′ R′, to be delivered, in so many turns of the helices, into the receiving chamber P.

Z is a pipe for supplying the water, for which there is an overflow at W. The sand being drowned or fully saturated in a given proportion, by varying the overflow W, gives the proper amount of water for each turn of the helices.

H are movable wooden shafts, which are placed in proper straps in the machine, and serve to hitch or harness a horse to the same when it has to be taken from one place to another, making it a perfect wagon.

The advantages claimed for the malaxator are the following:

First. The apparatus, having the receiving chamber P upon the ground, is fed easily, with little labor; and the part Q′, or delivery, being elevated, allows of a wheelbarrow or basket being placed under to receive the artificial stone paste. This inclination also causes a more powerful malaxation, by retarding the progress of the matter, owing to the specific gravity.

Second. The gearings are out of the way, away from sand, water, dust, &c.

Third. The helices having their blades interlaid, their action upon the materials is of quite a different character than when said helices are not thus conjugated.

Fourth. The sand is gauged by a register. The lime and the hydraulic cement, the coloring matter, texture giver, or any other material used, may be also fed automically, and the machine once set by the inspector, the product is invariably the same, besides saving the labor of a hand whose trustworthiness is required to obtain good results. The continuous

introduction, by small and regular quantities, of the different substances, and the constant amount of water supplied to the sand, place the materials in the best of circumstances for producing, by proper action of the helices, an excellent result, difficult to attain if the component ingredients had been thrown in by shovel or basketfuls at a time.

Two of these machines are in use in New York, making béton aggloméré, and produce excellent results. They are operated without the hoppers R′ R′ or the feeding screws and pulleys connected therewith, the materials, (cement, lime, and sand,) roughly mixed together dry, being thrown directly into the hopper T.

34. **Rammers.**—The rammers weigh from fifteen to twenty pounds, and are made by attaching blocks of hard wood to handles three and a half to four feet in length. They are plied in an upright position. The face is rectangular, measuring from two and a half to three inches by from seven to eight, and is covered with an iron plate.

35. To transport the mixed béton to the work under construction, wheelbarrows, when admissible, are generally used. Buckets, baskets, or hods are required when it has to be carried up ladders or steep ascents. In extensive operations it could be hoisted by the power which drives the mill.

36. The weights of the materials used in the original tables of this report are given below:

	Per cubic foot.	Per U. S. bushel.
	Pounds.	*Pounds.*
Boulogne Portland cement, loosely measured	77⅞ to 87½	97 to 109
Boulogne Portland cement, well shaken down	101 to 105½	127 to 131
German Portland cement, loosely measured	71.9 to 76¾	89 to 95
German Portland cement, well shaken down	93¾ to 98 1-6	116½ to 122
American Rosendale cement, loosely measured	54.1 to 59¾	67 to 74
American Rosendale cement, well shaken down	71¾ to 74 1-6	89 to 92
Theil hydraulic lime, loosely measured	57¼	71¼
Theil hydraulic lime, well shaken down	67½	84¼
Seilley hydraulic lime, loosely measured	43	54
Seilley hydraulic lime, well shaken down	53	66
Glen's Falls, N. Y., fat lime in powder, loosely measured	29¾	37½
Glen's Falls, N. Y., fat lime in powder, well shaken down	37	46
Coarse and fine pit sand, loosely measured, dry	94¼	117
Coarse and fine pit sand, well shaken down	104¼	129
The sand contained all sizes, up to 1-10 inch diameter		
Coarse gravel and pebble, loosely measured	101¼	126
Coarse gravel and pebble, well shaken down	108¾	135

The gravel was screened from everything smaller than a pea, and contained all sizes from that up to a pigeon's egg.

37. The relation existing between the *weight* and the *tensile strength* of Portland cement, already referred to, is shown in the following table, compiled from Mr. Grant's experiments in England. The principle that the strength increases with the weight has been quite thoroughly verified with Portland cements, recently made on a small scale in New York. The cements in the table contained no sand, were seven days old, (being the last six days in water,) and the sectional area of rupture was $2\frac{1}{4}$ square inches, reduced in table to 1 square inch.

TABLE I.—(*From Mr. Grant's experiments.*)

TENSILE STRENGTH OF ENGLISH PORTLAND CEMENTS OF VARIOUS WEIGHTS, WITHOUT SAND.

Weight of cement powder, loosely measured, per U. S. bushel.	Tensile strength per square inch; blocks 7 days old; in water 6 days.	Weight of cement powder, per U. S. bushel.	Tensile strength per square inch; blocks 7 days old; in water 6 days.
Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
103	236	117	319
105	290	119	286
107	311	121	363
109	308	123	338
111	312	125	408
113	330	126	406
115	315	....	....

38. The following table shows the tensile strength of Boulogne Portland and American Rosendale cements, separately, and also when mixed together in various proportions without sand. The Portland weighed, to the United States bushel, 97 pounds when loose, and 127 pounds when compacted by shaking, and the Rosendale 67 pounds loose and 90 pounds compacted. The Rosendale cement was made by the Lawrenceville Cement Company. The area of rupture was $2\frac{1}{4}$ square inches, reduced in the table to 1 square inch. The blocks were made with very little water and were rammed like béton aggloméré. They were seven days old, having been six days in water.

TABLE II.—(*From General Gillmore's experiments.*)

PROPORTIONS OF DRY INGREDIENTS.

No.	By weight.	By volume, loosely measured.	Tensile strength per square inch; blocks 7 days old; in water 6 days.
			Pounds.
1	Neat Portland cement		400
2	Portland cement, 1; Rosendale cement, $\frac{1}{8}$	Portland cement, 1; Rosendale cement, 0.18	411
3	Portland cement, 1; Rosendale cement, $\frac{1}{4}$	Portland cement, 1; Rosendale cement, 0.36	394
4	Portland cement, 1: Rosendale cement, $\frac{1}{2}$	Portland cement, 1; Rosendale cement, 0.72	392
5	Portland cement, 1; Rosendale cement, $\frac{3}{4}$	Portland cement, 1; Rosendale cement, 1.09	222
6	Portland cement, 1; Rosendale cement, 1	Portland cement, 1; Rosendale cement, 1.45	189
7	Portland cement, 1; Rosendale cement, $1\frac{1}{3}$	Portland cement, 1; Rosendale cement, 1.97	160
8	Portland cement, 1; Rosendale cement, 2	Portland cement, 1; Rosendale cement, 2.9	136
9	Portland cement, 1; Rosendale cement, 4	Portland cement, 1; Rosendale cement, 5.8	125
10	Portland cement, 1; Rosendale cement, 8	Portland cement, 1; Rosendale cement, 11.6	96
11	Neat Rosendale cement		72

39. The Rosendale cement of the foregoing table, is replaced by clean sharp sand in Table III, on the following page, all other conditions of Table II being carefully maintained, the samples being made with a small quantity of water and well rammed.

TABLE III.—(*From General Gillmore's experiments.*)

PROPORTIONS OF THE DRY INGREDIENTS.

No.	By weight.	By volume, loosely measured.	By volume, well-shaken.	Tensile strength per square inch; blocks 7 days old; in water 6 days.
				Pounds.
1	Neat Portland cement			400
2	Portland cement, 1: sand, $\frac{1}{8}$	Portland cement, 1; sand, 0. 1	Portland cement, 1; sand, 0. 12	379
3	Portland cement, 1; sand, $\frac{1}{4}$	Portland cement, 1; sand, 0. 21	Portland cement, 1; sand, 0. 25	377
4	Portland cement, 1; sand, $\frac{1}{2}$	Portland cement, 1; sand, 0. 42	Portland cement, 1; sand, 0. 5	320
5	Portland cement, 1; sand, $\frac{3}{4}$	Portland cement, 1; sand, 0. 6	Portland cement, 1; sand, 0. 7	262
6	Portland cement, 1; sand, 1	Portland cement, 1; sand, 0. 85	Portland cement, 1; sand, 0. 99	244
7	Portland cement, 1; sand, $1\frac{1}{8}$	Portland cement, 1; sand, 1. 13	Portland cement, 1; sand, 1. 3	179
8	Portland cement, 1; sand, 2	Portland cement, 1; sand, 1. 7	Portland cement, 1; sand, 1. 9	138
9	Portland cement, 1; sand, 4	Portland cement, 1; sand, 3. 4	Portland cement, 1; sand, 3. 9	97
10	Portland cement, 1; sand, 6	Portland cement, 1; sand, 5. 00	Portland cement, 1; sand, 5. 9	66
11	Portland cement, 1; sand, 8	Portland cement, 1; sand, 6. 8	Portland cement, 1; sand, 7. 8	39

The results given in Tables II and III are the averages obtained by testing several samples, generally four, of each particular mixture.

40. In preparing the following table, some of the samples were mixed with a very small quantity of water, and rammed into the mould, as described for making béton aggloméré, while others were made plastic like over-stiff mason's mortar, and pressed firmly into the mould with a trowel, care being taken in each case to render the mixture as compact as possible.

The results indicate, with great prominence, the advantages of using but a small amount of water, and of thorough ramming.

The proportions of dry ingredients by weight only are given, the corresponding proportion by volume having been recorded in Table II and III.

TABLE IV.—(*From General Gillmore's experiments.*)

No.	Proportions of dry ingredients, by weight.	How mixed and treated.	Tensile strength per sq. inch; blocks 7 days old; in water 6 days.
			Pounds.
1	Portland cement, 1; sand, $\frac{1}{4}$	Like béton aggloméré	377
2	Portland cement, 1; sand, $\frac{1}{4}$	Like common mortar	289
3	Portland cement, 1; sand, $\frac{1}{2}$	Like béton aggloméré	320
4	Portland cement, 1; sand, $\frac{1}{2}$	Like common mortar	222
5	Portland cement, 1; sand, 1	Like béton aggloméré	244
6	Portland cement, 1; sand, 1	Like common mortar	197
7	Portland cement, 1; sand, $1\frac{1}{3}$	Like béton aggloméré	179
8	Portland cement, 1; sand, $1\frac{1}{3}$	Like common mortar	129
9	Portland cement, 1; sand, 2	Like béton aggloméré	138
10	Portland cement, 1; sand, 2	Like common mortar	109
11	Portland cement, 1; sand, 6	Like béton aggloméré	66
12	Portland cement, 1; sand, 6	Like common mortar	35
13	Portland cement, 1; sand, 8	Like béton aggloméré	39
14	Portland cement, 1; sand, 8	Like common mortar	24
15	Rosendale cement, 1; Portland cement, $\frac{1}{8}$	Like béton aggloméré	96
16	Rosendale cement, 1; Portland cement, $\frac{1}{8}$	Like common mortar	40
17	Rosendale cement, 1; Portland cement, $\frac{1}{2}$	Like béton aggloméré	129
18	Rosendale cement, 1; Portland cement, $\frac{1}{2}$	Like common mortar	44

41. Tensile strength of cements made by the Newark and Rosendale Cement Company, mixed with little water and rammed into moulds like béton aggloméré.

TABLE V.—(*From General Gillmore's experiments.*)

PROPORTIONS FOR THE DRY INGREDIENTS.				Tensile strength per square inch; blocks 7 days old; in water 6 days.
No.	By weight.	By volume, loosely measured.	By volume, well-shaken.	*Pounds.*
1	Rosendale cement, pure.	....	....	72
2	Rosendale cement, 1; sand, 1.	....	....	51
3	Rosendale cement, 1; sand, 2.	Rosendale cement, 1; sand, 1.2.	Rosendale cement, 1; sand, 1.4.	40
4	Rosendale cement, 1; sand, 3.	Rosendale cement, 1; sand, 1.8.	Rosendale cement, 1; sand, 2.	33
5	Rosendale cement, 1; sand, 4.	Rosendale cement, 1; sand, 2.4.	Rosendale cement, 1; sand, 2.8.	22
6	Rosendale cement, 1; sand, 6.	Rosendale cement, 1; sand, 3.6.	Rosendale cement, 1; sand, 4.	(*)

* Less than 10 pounds.

The mixtures used for Table V were made with little water, and were in all respects manipulated and treated like béton aggloméré, as far as this could be done by hand. The point arrived at was to use as much water as possible without rendering the compound so wet that it could not be thoroughly compacted by rammings.

If water enough be used to make the mixtures plastic, like masons' mortar, the tensile strength is very greatly diminished, in proportion to the amount of water used.

42. The Rosendale cements vary greatly in quality from time to time, depending on the greater or less care used in selecting the stone from the several layers as they are taken out of the quarry.

It is only when special pains are taken in its manufacture that an article can be produced capable of sustaining a tensile strain of 70 pounds to the square inch upon blocks seven days old, made plastic like mortar, but without sand.

When made and compacted like béton aggloméré the strength is about doubled. The average quality ranges considerably below this strength, sometimes as low indeed as 25 pounds to the square inch. All the several brands may reach both these limits in the course of a single season. A tensile strength of 65 pounds to the square inch in seven days is seldom exceeded

by any of them, while, exceptionally, some are adulterated to a strength of only 18 pounds.

Samples of Rosendale cement brought to the New York market during the same week in the month of August, 1870, by five different companies were tested with the results recorded below in Table VI.

43. Tensile strength of several Rosendale cements, without sand, mixed to a stiff paste.

TABLE VI.—(*From General Gillmore's experiments.*)

	Tensile strenth per square inch; blocks seven days old; in water six days.
Number one	64 pounds.
Number two	65 pounds.
Number three	39 pounds.
Number four	39 pounds.
Number five	28 pounds.

44. Tables II, III, IV, V, and VI afford the means of comparing the tensile strength of Portland cement, in various combinations and under various conditions, with Rosendale cement similarly treated, the mixtures being in every case kept one day in the air and six days in water, and broken when seven days old.

The diagram, Plate I, shows the progressive increase of strength with age of Portland cement mortars, compiled from trustworthy authority.

It will be seen by inspection that the cements of the diagram were inferior, when seven days old, to those of Tables II and III, while they range between the strongest and weakest of those of Table I.

45. The mortars which furnished the following table (VII) were mixed in the summer of 1869, and were left in one of the casemates of Fort Tompkins, covered with sand, until fifteen months old, when they were broken. They were kept in a damp condition, but were never immersed in or wet with water. They therefore attained their age under circumstances not specially favorable to induration, and the results are not considered of great value.

The Portland cement weighed 98 pounds, the American cements 67 to 68 pounds, and the sand 114 pounds to the bushel, loosely measured. The lime was the common or fat lime from Glen's Falls, New York, and was slaked to a paste. The several mixtures were made up soft, like masons' mortar, and therefore could not be compacted by ramming, like béton aggloméré.

TABLE VII.—(*From General Gillmore's experiments.*)

No.	Proportions of ingredients, by volume.	Tensile strength per square inch; blocks 15 months old.
		Pounds.
1	Boulogne Portland cement, without sand	496
2	Delafield & Baxter's Rosendale cement, without sand	154
3	Bondurant & Ford's Louisville cement, without sand	151
4	Coplay (Pennsylvania) cement, without sand	139
5	Boulogne Portland cement, 1; sand, 1	320
6	Boulogne Portland cement, 1; sand, 3	160
7	Delafield & Baxter's Rosendale cement, 1; sand, 1	132
8	Delafield & Baxter's Rosendale cement, 1; sand, 3	63
9	Bondurant & Ford's Louisville cement, 1; sand, 1	123
10	Bondurant & Ford's Louisville cement, 1; sand, 3	51
11	Coplay (Pennsylvania) cement, 1; sand, 1	81
12	Portland cement paste, 1; fat lime paste, 1: of this mixture, 1 volume; of sand, 3 volumes.	80
13	Delafield & Baxter's cement paste, 1; fat lime paste, 1: of this mixture, 1 volume; of sand, 3 volumes.	39
14	Bondurant & Ford's cement paste, 1; fat lime paste, 1: of this mixture, 1 volume; of sand, 3 volumes.	44
15	Coplay cement paste, 1; fat lime paste, 1: of this mixture, 1 volume; of sand, 3 volumes.	31

46. Some trials of artificial Portland cement, manufactured at Stettin, Germany, weighing 89 pounds to the United States bushel, loosely measured, and 122 pounds when well compacted by shaking, gave the results recorded in Table VIII.

TABLE VIII.—(*From General Gillmore's experiments.*)

No.	Proportions of the dry ingredients. By weight.	Proportions of the dry ingredients. By volumes, loosely measured.	Proportions of the dry ingredients. By volumes, well-shaken.	Tensile strength per sq. inch; blocks 7 days old; in water 6 days.
				Pounds.
1	Portland cement, neat			240
2	Portland cement, 1; sand, 2	Portland cement, 1; sand, 1.5	Portland cement, 1; sand, 1.9	198
3	Portland cement, 1; sand, 4	Portland cement, 1; sand, 3.7	Portland cement, 1; sand, 3.8	115
4	Portland cement, 1; sand, 6	Portland cement, 1; sand, 4.6	Portland cement, 1; sand, 5.7	70
5	Portland cement, 1; sand, 8	Portland cement, 1; sand, 6.2	Portland cement, 1; sand, 7.5	24
6	Portland cement, 1; sand, 10	Portland cement, 1; sand, 7.7	Portland cement, 1; sand, 9.4	20
7	Portland cement, 1; sand, 1; pebbles, 1	Portland cement, 1; sand and pebbles, 1.5	Portland cement, 1; sand and pebbles, 1.8	182
8	Portland cement, 1; sand, 2; pebbles, 2	Portland cement, 1; sand and pebbles, 3.	Portland cement, 1; sand and pebbles, 3.7	135
9	Portland cement, 1; sand, 3; pebbles, 3	Portland cement, 1; sand and pebbles, 4.5	Portland cement, 1; sand and pebbles, 5.5	127
10	Portland cement, 1; sand, 4; pebbles, 4	Portland cement, 1; sand and pebbles, 6.	Portland cement, 1; sand and pebbles, 7.4	78
11	Portland cement, 1; sand, 5; pebbles, 5	Portland cement, 1; sand and pebbles, 7.4	Portland cement, 1; sand and pebbles, 9.2	52
12	Portland cement, 1; sand, 6; pebbles, 6	Portland cement, 1; sand and pebbles, 9.	Portland cement, 1; sand and pebbles, 11.	51
13	Portland cement, 1; sand, 5 Fat lime powder, $\frac{1}{8}$; pebbles, 5	Portland cement, 1; Fat lime powder, $\frac{4}{10}$; Sand and pebbles, 7.4		61
14	Portland cement, 1; sand, 6 Fat lime powder, $\frac{1}{4}$; pebbles, 6	Portland cement, 1; Fat lime powder, $\frac{8}{10}$; Sand and pebbles, 9		66

47. All attempts to cheapen a matrix of Portland cement, by the *substitution* of common lime for a portion of the cement, result in a sacrifice of strength in proportion to the extent of the adulteration, and the ratio of loss is not materially changed by the increased induration due to age. This is specially true in thick walls or other large masses of masonry, of which the portion which hardens by desiccation, and the absorption of carbonic acid at the surface, forms but a small proportion of the entire mass.

When, however, the matrix is cement alone, and the proportion of sand is so large that the grains are not all coated, and the voids not all filled or nearly so, increased strength of the mortar béton is secured by *adding* a small quantity of common lime. The result is that both the strength of the matrix and the porosity of the mixture are diminished. The aggregate volume, however, remains the same, while the section of rupture upon the same area, and the rupturing force, are both augmented.

In other words, with large doses of sand and a cement matrix—for example, when the volume of the sand exceeds five times that of the cement loosely measured—there is an advantage in increasing the volume of the matrix at the expense of its strength, by adding common lime powder, within the limits generally of one-fourth of the weight, or eight-tenths of the volume, of the cement.

48. The following table shows the effect which common lime powder, added to Boulogne Portland cement, has upon the tensile strength of blocks one week old. The materials were mixed together with a small amount of water, as much, however, as they would take without becoming plastic. The mixture was firmly compacted in the moulds by ramming.

TABLE IX.—(*From General Gillmore's experiments.*)

No.	Proportions of the dry ingredients. By weight.	Proportions of the dry ingredients. By volume, loosely measured.	Tensile strength per sq. inch; blocks 7 days old; in water 5 days.
			Pounds.
1	Portland cement, neat		481*
2	Portland cement, 1 Common lime powder, $\frac{1}{8}$	Portland cement, 1 Common lime powder, 0.4	291
3	Portland cement, 1 Common lime powder, $\frac{1}{4}$	Portland cement, 1 Common lime powder, 0.8	281
4	Portland cement, 1 Common lime powder, $\frac{1}{2}$	Portland cement, 1 Common lime powder, 1.6	176
5	Portland cement, 1 Common lime powder, $\frac{3}{4}$	Portland cement, 1 Common lime powder, 2.4	132

*Portland cement rarely attains this strength in seven days.

49. Strength of English Portland cement to resist compression; from trials with bricks $2\frac{3}{4}$ inches thick, 9 inches long, and $4\frac{1}{4}$ inches wide; area under pressure, 9 inches $\times$ $4\frac{1}{4}$ inches, equal to an area of $38\frac{1}{4}$ inches.

TABLE X.—(*From Mr. Grant's experiments.*)

Proportions.	Age of bricks.	Total crushing weight.	Crushing weight per square inch.
		Tons.	*Pounds.*
Neat cement	3 months	65	3,806.5
1 volume cement, 1 volume sand	3 months	43	2,518.3
1 volume cement, 2 volumes sand	3 months	34	1,991.2
1 volume cement, 3 volumes sand	3 months	24	1,405.6
1 volume cement, 4 volumes sand	3 months	23	1,347.0
1 volume cement, 5 volumes sand	8 months	16	938.0
Neat cement	6 months	92	5,388.0
1 volume cement, 1 volume sand	6 months	59	3,455.3
1 volume cement, 2 volumes sand	6 months	47	2,752.6
1 volume cement, 3 volumes sand	6 months	37	2,167.0
1 volume cement, 4 volumes sand	6 months	31	1,815.5
1 volume cement, 5 volumes sand	6 months	26	1,522.7
Neat cement	9 months	102	5,973.6
1 volume cement, 1 volume sand	9 months	78	4,568.0
1 volume cement, 2 volumes sand	9 months	62	3,631.0
1 volume cement, 3 volumes sand	9 months	41	2,401.2
1 volume cement, 4 volumes sand	9 months	33	2,225.5
1 volume cement, 5 volumes sand	9 months	29	1,698.4

The foregoing table (Table X) is defective in that it does not give the weight of the cement employed in the trials.

The tensile strength of Portland cements, as already stated, may be doubled by a judicious increase of the intensity of the heat in burning, and the presumption is that their capacity to resist compression may be augmented, possibly to as great a degree, by the same means.

50. The strength of Boulogne Portland, and American Rosendale cements to resist compression is shown in the following table, from tests applied to blocks $3\frac{1}{2}$ inches wide, $5\frac{1}{2}$ inches long, and 3 inches thick, the area under pressure being $19\frac{1}{4}$ square inches.

The Portland cement weighed 127 pounds, and the Rosendale 92 pounds to the United States bushel, both being well compacted by shaking. When tested, the blocks were seven days old, having been six days in water. Some of them were made with little water and thoroughly *rammed*, like béton aggloméré; others were treated like over-stiff masons' mortar, firmly pressed into the moulds with a trowel.

The Rosendale cement was manufactured by Messrs. Delafield & Baxter, at High Falls, Ulster County, New York.

TABLE XI.—(*From General Gillmore's experiments.*)

No.	Proportions of the dry ingredients. By weight.	Proportions of the dry ingredients. By volume.	How mixed and treated.	Crushing weight per area of 19¼ sq. inches; blocks 7 days old; in water 6 days.	Crushing weight per square inch.
					Pounds.
1	Rosendale cement. No sand		Like béton aggloméré	6. 25 gross tons	727. 3
2	Rosendale cement. No sand		Like common mortar	0. 90 gross ton	104. 7
3	Portland cement. No sand		Like béton aggloméré	24. 55 gross tons and not crushed.	2, 846. 7
4	Portland cement. No sand		Like common mortar	22. 32 gross tons	2, 597. 2
5	Rosendale cement, 1; sand, 2	Rosendale cement, 1; sand, 1. 2	Like béton aggloméré	2. 67 gross tons	310. 7
6	Rosendale cement, 1; sand, 2	Rosendale cement, 1; sand, 1. 2	Like common mortar	0. 45 gross ton	52. 4
7	Portland cement, 1; sand, 2	Portland cement, 1; sand, 1. 7	Like béton aggloméré	24. 10 gross tons	2, 804. 4
8	Portland cement, 1; sand, 2	Portland cement, 1; sand, 1. 7	Like common mortar	8. 92 gross tons	1, 038. 0
9	Rosendale cement, 1; sand, 3	Rosendale cement, 1; sand, 1. 8	Like béton aggloméré	1. 00 gross ton	116. 4
10	Rosendale cement, 1; sand, 3	Rosendale cement, 1; sand, 1. 8	Like common mortar	0. 53 gross ton	61. 7
11	Portland cement, 1; sand, 3	Portland cement, 1; sand, 2. 55	Like béton aggloméré	12. 50 gross tons	1, 454. 5
12	Portland cement, 1; sand, 3	Portland cement, 1; sand, 2. 55	Like common mortar	8. 47 gross tons	985. 6
13	Rosendale cement, 1; sand, 4	Rosendale cement, 1; sand, 2. 35	Like béton aggloméré	1. 34 gross tons	156. 0
14	Rosendale cement, 1; sand, 4	Rosendale cement, 1; sand, 2. 35	Like common mortar	Went to pieces in water	
15	Portland cement, 1; sand, 4	Portland cement, 1; sand, 3. 4	Like béton aggloméré	8. 00 gross tons	931. 0
16	Portland cement, 1; sand, 4	Portland cement, 1; sand, 3. 4	Like common mortar	6. 25 gross tons	727. 3
17	Rosendale cement, 1; sand, 6	Rosendale cement, 1; sand, 3. 5	Like béton aggloméré	0. 45 gross ton	52. 4
18	Rosendale cement, 1; sand, 6	Rosendale cement, 1; sand, 3. 5	Like common mortar	Went to pieces in water	
19	Portland cement, 1; sand, 6	Portland cement, 1; sand, 5	Like béton aggloméré	4. 46 gross tons	519. 0
20	Portland cement, 1; sand, 6	Portland cement, 1; sand, 5	Like common mortar	2. 23 gross tons	259. 5
21	Rosendale cement, 1; sand, 8	Rosendale cement, 1; sand, 4. 7	Like béton aggloméré	0. 40 gross ton	46. 5
22	Rosendale cement, 1; sand, 8	Rosendale cement, 1; sand, 4. 7	Like common mortar	Went to pieces in water	
23	Portland cement, 1; sand, 8	Portland cement, 1; sand, 6. 8	Like béton aggloméré	2. 23 gross tons	259. 5
24	Portland cement, 1; sand, 8	Portland cement, 1; sand, 6. 8	Like common mortar	0. 90 gross ton	104. 7

Remarks on the trials which furnished the Table XI.

The blocks were crushed in a hydraulic press. They rested upon a thin layer of dry sand, in order to secure a better bearing. Sand was also spread evenly over the top surface of each block. Owing to inaccuracies in their form, and inequalities in the bearing surface, the tendency of the strain, when first applied, was to break the blocks transversely, long before the ultimate crushing weight was reached. In practice it is almost as difficult to guard against the error thus introduced as it is to compute its value. The circumstances attending the trials are therefore recorded as they occurred, as follows:

No. 1. Cracked in two at 5,000 pounds, and crushed into several pieces at 14,000 pounds.

No. 2. Crushed into several pieces at 2,000 pounds.

No. 3. One transverse crack at 35,000 pounds, dividing the block into two pieces. Another crack at 55,000 pounds through one of the pieces. No more pressure could be produced by the machine. The block was removed in three solid pieces, but was not crushed.

No. 4. Cracked at 38,000 pounds, and crushed into several pieces at 50,000 pounds.

No. 5. Cracked at 3,000 pounds, and crushed into many pieces at 6,000 pounds.

No. 6. Cracked at 600 pounds, and crushed at 1,000 pounds.

No. 7. Cracked at 32,000 pounds, and crushed at 54,000 pounds; one piece being about one-third the volume of the entire block.

No. 8. Cracked at 10,000 pounds, and went into pieces at 20,000 pounds.

No. 9. Crushed into many pieces at 2,200 pounds.

No. 10. Crushed into many pieces at 1,200 pounds.

No. 11. One crack at 8,000 pounds, another at 26,000 pounds, and crushed suddenly into five pieces at 28,000 pounds.

No. 12. One crack at 12,000 pounds, another at 17,000 pounds, and crushed at 19,000 pounds.

No. 13. One crack at 1,000 pounds, and crushed at 3,000 pounds.

No. 15. One crack at 7,000 pounds, another at 13,000 pounds, and crushed into many pieces at 18,000 pounds.

No. 16. Cracked at 9,000 pounds, and crushed into many pieces at 14,000 pounds.

No. 17. Crushed into small pieces at 1,000 pounds.

No. 19. Crushed into pieces at 10,000 pounds.

No. 20. Crushed into pieces at 5,000 pounds.

No. 21. Crushed into pieces at 9,000 pounds.

No. 23. Crushed into pieces at 5,000 pounds.

No. 24. Crushed into pieces at 2,000 pounds.

51. The following table (XII) shows the strength to resist compression, of béton or concrete composed of cement, sand, gravel, and pebbles. The gravel and pebbles were procured by screening gravel from the sea-shore so as to remove everything smaller than one-eighth to one-sixth of an inch in diameter. It varied from the size of a pea to that of a pigeon's egg, and weighed

126 pounds to the even United States bushel, loosely measured, and 135 pounds when well compacted by shaking. The cements and sand were of the same quality used in the former tables. The concrete blocks were formed by first incorporating the dry cement with the dry sand, and then adding sufficient water to convert the mixture into an over-stiff mortar. The mortar and gravel were then put into a cylindrical wooden bucket, with a close-fitting top, and mixed together by prolonged shaking, the bucket being revolved repeatedly during the operation, after which the concrete was rammed into moulds and left for twenty-four hours to harden. The blocks were never immersed in water, but were wet with a sponge every day, and crushed when ten days old.

TABLE XII.—(*From General Gillmore's experiments.*)

No.	Proportions of the dry ingredients, by volume.	Size of blocks. Length.	Breadth.	Height.	Total crushing weight, in pounds.	Crushing weight per square inch, in pounds. Blocks 10 days old.
		In.	*In.*	*In.*		
1	Boulogne Portland cement.. 1 Sand .... 3 Coarse gravel and pebbles.. 9	5 7-16	3½	3	8, 600 9, 400	452 494
2	Boulogne Portland cement.. 1 Sand .... 4 Coarse gravel and pebbles.. 9	5 7-16	3½	3	5, 600 7, 400	294 388
3	Boulogne Portland cement.. 1 Sand .... 4 Coarse gravel and pebbles..10	5 7-16	3½	3	7, 000 8, 000	367 420
4	Boulogne Portland cement.. 1 Sand .... 5 Coarse gravel and pebbles..13	5 7-16	3½	3	8, 600 6, 600	452 347
5	Boulogne Portland cement.. 1 Sand .... 4 Coarse gravel and pebbles..14	5 7-16	3½	3	5, 833⅓ 4, 666⅔ 4, 166⅔	306 245 218
6	Boulogne Portland cement. 1 Sand .... 6 Coarse gravel and pebbles..15	5 7-16	3½	3	7, 000 4, 560	367 239
7	Boulogne Portland cement.. 1 Sand .... 5 Coarse gravel and pebbles..16	5 7.16	3½	3	5, 040 4, 500 5, 760	265 237 303
8	Norton's Rosendale cement. 1 Sand .... 3 Coarse gravel and pebbles.. 6	8	3½	3	8, 200	293, (av'ge of 2 trials.)
9	Norton's Rosendale cement. 1 Sand .... 3 Coarse gravel and pebbles.. 9	8	3½	3	3, 200	114, (av'ge of 3 trials.)
10	Norton's Rosendale cement. 1 Sand .... 4 Coarse gravel and pebbles.. 9	8	3½	3	3, 400	121, (av'ge of 4 trials.)
11	Norton's Rosendale cement. 1 Sand .... 4 Coarse gravel and pebbles..10	8	3½	3	2, 000	71, (high'st of 2 trials.)

PROPERTIES OF BÉTON AGGLOMÉRÉ.

STRENGTH.

52. The most trustworthy report hitherto published upon the strength of béton aggloméré to resist a crushing weight, is that of Mr. P. Michelot, ingénieur-in-chef des Ponts et Chaussées, from experiments made at the Conservatoire Impérial des Arts et Métiers, France, in July, 1864.

The results of these trials are given in the following table.

TABLE XIII.

Date of fabrication and age of samples.	Composition of the samples in volumes of ingredients.		DIMENSIONS OF SAMPLES, IN INCHES. Length.	Breadth.	Height.	Weight per cub. foot.	CRUSHING STRENGTH, IN POUNDS. Total.	Per sq. inch.
						Lbs.		
1 * Feb., 1862, 30 months.	River sand Hydraulic lime of Argentieul Cement, (Schacher & Letellier)	4 1 ½	3 2	2½ 1	3¼	130	28, 240 37, 744	3, 270 4, 131
2 * Jan., 1862, 31 months.	Coarse river sand Hydraulic lime of Argentieul Cement, (as above)	5 1 ¾	3 2	2¼ 1¼	2¼	132	46, 641	4, 546
3 * Jan., 1862, 31 months.	River sand Hydraulic lime of Argentieul Cement, (as above)	5 1 ⅓	3	2	3¼	130	24, 893	4, 172
4 * Feb., 1863, 18 months.	Sand Lime, (as above) Cement, (as above)	5 1 1	3 2	2¼ 1	3¼	139	34, 639	4, 040
5 Feb., 1862, 30 months.	Coarse sand Lime, (hydraulic,) of Theil Portland cement, (Boulogne)	4 1 ½	4	3¼	4	142	72, 458	5, 650
6 Nov., 1862, 21 months.	Mixed sand Hydraulic lime of Theil Boulogne Portland cement	4 1 ¾	3	2¼	3¼	146	46, 875 50, 110	7, 176 7, 495
7 * Nov., 1862, 21 months.	Coarse sand, washed Hydraulic lime of Argentieul Boulogne Portland cement	4 1 ¾	3 2	2¼ 1	3	141	48, 019	5, 549
8 * Nov., 1862, 21 months.	Coarse sand, washed Hydraulic lime of Argentieul Portland c'mt, (Schacher & Letellier)	4 1 ¾	3 2	2¼ 1	3¼	140	33, 467	5, 364
9 * May, 1863, 15 months.	Sand of Vesinet Hydraulic lime of Argentieul Hydraulic c'mt, (Schacher & Letellier)	4 1 ¼	3 2	2¼ 1	3¼	133	23, 462	2, 682
10 * May, 1863, 15 months.	Sand of Vesinet Hydraulic lime of Argentieul Hydraulic c'mt, (Schacher & Letellier)	4 1 ¼	3 2	2¼ 1	3¼	139	23, 052	2, 634

Explanation of Table XIII.

The samples marked thus (*) are pieces of blocks previously broken by a tensile strain, and have the form of the letter **T**, and the double numbers in the columns of length and breadth indicate the dimensions of the two rectangles composing the total area under compression.

No. 1. Fissured. This béton was the same composition as that used in the vaults of the city barracks, Paris.

No. 2. The small lateral prism was first crushed. The other resisted the pressure, but was wrenched by having an unequal bearing.

No. 3. One of the lower angles of the sample was imperfect, having been injured before the trial.

Nos. 9 and 10 were of the same composition as the béton used in the church of Vesinet.

53. The blocks which furnished the following table were crushed in November, 1870. They were cut from sills, steps, platforms, &c., that had been exposed to the weather from the time they were made. During warm dry weather they were wet every day with a hose.

TABLE XIV.—(*From General Gillmore's experiments.*)

No.	Composition of samples in volumes of ingredients.	Age of sampl's.	Dimensions of samples. Length.	Breadth.	Height.	Weight p'r cub. ft.	Crushing strength, in pounds. Total.	Per sq. inch.
		Months.	*In.*	*In.*	*In.*			
1	Pit sand ....5 Hydraulic lime of Seilley....1 Boulogne Portland cement..1½	2	3	4	3	......	19,000	1,583⅓
2	Pit sand ....5 Hydraulic lime of Seilley....1 Boulogne Portland cement..1½	2	3	4	3	......	18,000	1,500
3	Pit sand ....5 Hydraulic lime of Seilley....1 Boulogne Portland cement..1½	2	4	4	3	......	27,000	1,687½
4	Pit sand ....5 Hydraulic lime of Seilley....1 Boulogne Portland cement..1½	2	4	4	3	......	32,000	2,000
5	Pit sand ....5 Hydraulic lime of Seilley....1 Boulogne Portland cement..1	3	3	4	3	......	22,000	1,833⅓
6	Pit sand ....5 Hydraulic lime of Seilley....1 Boulogne Portland cement..1	3	4	4	3	......	26,000	1,625
7	Pit sand ....5 Hydraulic lime of Seilley....1 Boulogne Portland cement..1	3	4	4	3	......	34,000	2,125
8	Pit sand ....5 Hydraulic lime of Seilley....1 Boulogne Portland cement..1	3	4	4	3	......	31,000	1,937½
9	Pit sand ....5 Hydraulic lime of Seilley....1 Boulogne Portland cement..1	3	4	4	3	......	28,000	1,750
10	Pit sand ....5 Hydraulic lime of Seilley....1 Boulogne Portland cement.. ½	4½	3	4	3	......	18,000	1,500
11	Pit sand ....5 Hydraulic lime of Seilley....1 Boulogne Portland cement.. ½	4½	3	4	3	......	17,000	1,416⅔
12	Pit sand ....5 Hydraulic lime of Seilley....1 Boulogne Portland cement..½	4½	4	4	3	......	23,000	1,437½

54. Resistance to crushing of bricks and natural stone. (From Professor Rankine's tables and other trustworthy sources.)

TABLE XV.

Materials.	Crushing weight per square inch, in pounds.
Brick, weak red	550 to 800
Brick, strong red	1,100
Brick, first quality hard	2,000 to 4,368
Brick, fire	1,700
Chalk	330
Granite, Patapsco	5,340
Granite, Quincy	15,300
Marble, Montgomery County, Pennsylvania	8,950
Limestone, granular	4,000 to 4,500
Limestone, marble	5,500
Sandstone, strong	5,500
Sandstone, ordinary	3,300 to 4,400
Sandstone, Connecticut	3,319
Caen stone	1,088

DURABILITY.

55. **Constructions on land.**—Béton aggloméré—or any mixture of cement and sand, or cement, lime, and sand, tempered with just sufficient water to convert all the matrix into a thick viscous paste—resists climatic influences and changes, and other usual causes of deterioration in masonry, better than any other combination of the same ingredients, in which more than this minimum quantity of water is used. This is more emphatically the case when the proportion of water is so great that the mixture becomes plastic, like masons' mortar. This fact is not only obvious, but is amply confirmed by experience and observation.

Only a fixed equivalent of water can combine with any given quantity and variety of cement or lime.

In béton or mortar any excess soon evaporates, if exposed to the air, leaving the mass porous, and therefore liable to injury from various agencies, and particularly from frost. If immersed in sea water, a larger surface is exposed to the action of alkalies and acids, known to be more or less injurious in their effects upon light and porous mortars.

The densest mortars that can be produced from given materials are the best, and the use of a large amount of water is incompatible with the condition of density.

The best pointing mortar, indeed, is a béton aggloméré, answering fully to the description of that material, being prepared with a small proportion of water, and applied by caulking it into the joints. In northern climates it has to sustain the severest tests to which masonry of any description can be exposed; to alternations of cold and heat, moisture and dryness, freezing and thawing.

Béton aggloméré, when the volume of matrix is so adjusted that the voids in the sand are completely filled—say in the proportion generally of one of the matrix to two and a half or three of sand—becomes in process of time as impervious to water as many of the compact natural stones, while its matured strength exceeds that of the best qualities of sandstone, some of the granites, and many of the limestones and marbles.

Chemical tests have shown this béton to be practically impervious to water. Two small specimens, each weighing about $2\frac{1}{2}$ grammes, were tried by Dr. Isidor Walz, chemist, of New York City. Their specific gravity was 2.305. They were immersed in water fifteen minutes, and then kept four days in air, saturated with moisture. One of the specimens did not increase in weight at all during the interval, while the other absorbed $\frac{16}{100}$ of one per cent. of moisture.

This material, therefore, possesses all the characteristic properties of durability, being dense, hard, strong, and homogeneous; and there would appear to be no reason for supposing that it may not, with entire safety, be applied to out-door constructions, even in the most northerly portions of the United States.

It is injured by freezing before it has had time to set. Important works should not, therefore, be executed during the winter in cold climates.

The effect of freezing on newly made béton is to detach a thin scale from the exposed surface, producing a rough and unsightly appearance; but the injury does not extend into the mass of the material, unless the frost be very intense.

In monolithic constructions, the plank coffre affords sufficient protection to the face surfaces of the work against moderate frost, and, when the temperature ranges generally not much lower than the freezing point during the day, work may be safely carried on, if care be taken to cover over the new

material at night. After it has once set, and has had a few hours to harden, neither severe frost, nor alternate freezing and thawing, has any perceptible effect upon it, and, under any and all circumstances, it is much less liable to injury from these causes, and requires fewer precautions for its protection against them, than common hydraulic concrete.

Monolithic constructions in béton aggloméré may advantageously be carried on whenever it is not too cold to lay first-class brick masonry.

In Paris and vicinity operations are not generally suspended during the winter, unless the cold be unusually severe for that climate.

Pieces of statuary, and other specimens ornamented with delicate tracery, have been exposed for five consecutive winters to the weather in New York City, without undergoing the slightest perceptible change.

56. **Constructions in the sea.**—The power possessed by béton aggloméré of resisting the solvent action of salts (principally the sulphates of magnesia and soda) and certain gases contained in sea water, rests upon analogy rather than upon proof based upon adequate experience and observation.

Eminent European engineers do not hesitate to use Portland cement concrete, mixed with a comparatively large dose of water, for very important submarine constructions. The matrix of this concrete possesses less density and strength than that of béton aggloméré, and if the lime be excluded from the latter, the induration in the two cases would be due to precisely the same chemical action. The materials are indeed identical in composition under this condition, with the exception that there is an excess of water, and consequently an element of weakness, in the English concrete, which do not attach to the béton. The durability of the latter in sea water, without being much discussed, has been very generally conceded.

Monolithic constructions under water cannot be executed in béton aggloméré, for the reason that the prescribed ramming in thin layers would necessarily have to be omitted, and some other mode of compacting the mixture followed. This material, however, when laid green through water, loses its distinct name and character, as well as its superior strength and hardness, and becomes common béton or concrete, with the coarser ballast omitted. Its use in this form certainly offers no advantages with regard to strength, while in point of economy the usual

proportions of matrix, sand and shingle, or broken stone, is preferable.

57. **Uses of béton aggloméré in Europe and elsewhere.**—The most important and costly work that has yet been undertaken in this material is a section, thirty-seven miles in length, of the Vanne aqueduct, for supplying water to the city of Paris.

This aqueduct, which traverses the forest of Fontainbleau through its entire length, comprises two and a half to three miles of arches, some of them as much as fifty feet in height, and eleven miles of tunnels, nearly all constructed of the material excavated, the impalpable sand of marine formation known under the generic name of Fontainbleau sand. It includes, also, eight or ten bridges of large span (seventy-five to one hundred and twenty-five feet) for the bridging of rivers, canals, and highways.

The smaller arches are half circles, and are generally of a uniform span of $39\frac{37}{100}$ feet, with a thickness at the crown of $15\frac{3}{4}$ inches. Their construction was carried on without interruption through the winter of 1868–'69 and the following summer, and the character of the work was not affected by either extreme of temperature. The spandrels are carried up in open work to the level of the crown, and upon the arcade thus prepared the aqueduct pipe is moulded in the same material, the whole becoming firmly knit together into a perfect monolith. The pipe is circular, $6\frac{1}{2}$ feet in interior diameter, with a thickness of 9 inches at the top, and 12 inches at the sides, at the water surface. The construction of the arches is carried on about two weeks in advance of work on the pipe, and the centres are struck about a week later.

Water was let into a portion of this pipe in the spring of 1869, and M. Belgrand, inspector general of bridges and highways, and director of drainage and sewers of the city of Paris, certified that "*the impermeability appeared complete.*"

For details and general views of this aqueduct, see Plates IV, V, and VI.

58. Another interesting application of this material has been made in the construction, completed or very nearly so, of the light-house at Port Said, Egypt. It will be one hundred and eighty feet high, without joints, and resting upon a monolithic block of béton, containing nearly four hundred cubic yards. In design it is an exact copy of the Baleines light-house, executed

after the plans and under the orders of M. Léonce-Regnaud, engineer-in-chief.

59. An entire Gothic church, with its foundations, walls, and steeple, in a single piece, has been built of this material at Vesinet, near Paris. The steeple is one hundred and thirty feet high, and shows no cracks or other evidences of weakness.

M. Pallu, the founder, certifies that "during the two years consumed by M. Coignet in the building of this church, the béton aggloméré, in all its stages, was exposed to rain and frost, and that it has perfectly resisted all variations of temperature."

The entire floor of the church is paved with the same material, in a variety of beautiful designs, and with an agreeable contrast of colors.

60. In constructing the municipal barracks of Notre Dame, Paris, the arched ceilings of the cellars were made of this béton, each arch being a single mass. The spans varied from twenty-two to twenty-five feet, the rise, in all cases, being one-tenth the span, and the thickness at the crown 8.66 inches. In the same building the arched ceilings of the three stories of galleries, one above the other, facing the interior, and all the subterranean drainage, comprising nearly six hundred yards of sewers, are also monoliths of béton.

One of these vault arches, having a span of 17½ feet, was subjected to three severe trial tests, viz:

First. A pyramid of stone-work weighing thirty-six tons, of 2,000 pounds each, was placed on the centre of the vault.

Second. A mass of sand thirteen feet thick was spread over the surface of the same vault.

Third. Carts loaded with heavy materials were driven over it.

In no instance was the slightest effect produced.

61. A portion of the basement work of the Paris Exposition building comprised a system of groined arches, supported by columns about 13¾ inches square and 10 feet apart. The arches, having a uniform rise of one-tenth the span, and a thickness at the crown of 5½ inches, are monoliths of béton aggloméré. A system of flat cylindrical arches, of ten feet span, covers the ventilating passages. They have a rise of one-tenth, and a thickness at the crown of not quite 8 inches, and were tested with a distributed weight of 3,300 pounds to the superficial yard.

There was consumed in the construction of this basement-work more than 353,000 cubic feet of béton.

62. Over thirty-one miles of the Paris sewers had been laid in this material prior to June, 1869, at a saving of 20 per cent. on their lowest estimated cost, in any other kind of masonry.

The composition of the béton was as follows:

Sand, 5 measures.

Hydraulic lime, 1 measure.

Paris cement, (said to be as good as Portland cement,) $\frac{1}{5}$ measure.

63. Several large city houses, some for places of residence, and others for business purposes, have been constructed, and many others are in contemplation. In these the entire masonry, comprising both the exterior and the partition walls, the chimneys with flues, cellar arches, cistern, &c., is a single monolith of béton aggloméré.

In one house, having a cellar below the street level, and six full stories, surmounted with a Mansard roof above, the thickness of the exterior wall was established as follows, viz: cellar, 19.7 inches; first story, 15.7 inches; second story, 13.8 inches; third story, 12.8 inches; fourth story, 11.8 inches; fifth story, 10.8 inches; sixth story, 9.8 inches.

The cellars of such houses are usually divided into two large compartments by a wall parallel to the street, and these are covered by a flat arch of béton, the usual proportions of which are a rise of one-tenth the span, a thickness at the crown of $5\frac{1}{4}$ to $5\frac{1}{2}$ inches, and a thickness at the springing line of $8\frac{1}{2}$ to 9 inches. (See Plate VII.)

Spaces not exceeding thirteen or fourteen feet in width may be spanned by flat platforms from ten to twelve inches thick, and, similarly, the pavements of sidewalks may be in one continuous piece of béton, with street vaults below.

64. An interesting application of this material in the construction of a hollow sustaining wall was made at the cemetery of Passy, in supporting a bank of earth $29\frac{1}{2}$ feet in height. In that wall the volume of the hollows is equal to 53 per cent. of the aggregate volume of béton. The hollows were filled with dry earth. (See Plate VIII.)

65. The jetties at the entrance of the Suez Canal are built of béton aggloméré of cheap quality, composed of hydraulic lime of Theil and the almost impalpable sand of the desert. The construction is not monolithic, the béton having been formed into blocks weighing about twenty tons each on land, where they were allowed to harden for two or three months before

they were used. The blocks cost in final position one thousand francs apiece, or about $15 75 per cubic yard. The jetties are twenty-six yards wide at the base and six yards wide at the summit, and are twelve yards in height. About sixteen thousand blocks have thus far been used in their construction, and but little remains to be done toward their completion.

A better quality of béton, containing a small amount of Portland cement, would have been employed by most engineers for immersion in the sea, and would perhaps have been dictated by prudence.

66. All the works above referred to, except those at Port Said, were visited by the writer in the month of February, 1870, and these statements are based upon close observation and personal knowledge.

Many other interesting applications of this material were examined, of which it is not deemed necessary to make any special mention, except that in combined stability, strength, beauty, and cheapness, they far surpass the best results that could have been achieved by the use of any other materials, whether stone, brick, or wood.

In the numerous and varied applications which have been made of it in France, it has received the most emphatic commendations from the government engineers and architects.

67. For warehouses, churches, and large buildings of every description; for foundations, quay walls, light-houses, jetties, and piers; for abutments and massive walls of all kinds; for sidewalks, platforms, and flagging, and for many other minor purposes, béton aggloméré possesses not only great comparative cheapness, but all the essential merits of brick and stone with respect to strength, hardness, and durability; while for many purposes, such as cellars and cellar floors; cisterns, reservoirs, tanks, and fountains; arches, vaulted ceilings, and vaults; tunnels, aqueducts, sewer and water pipes, and ornamental work of every description within the province of the architect or engineer, it possesses advantages peculiar to itself, and not equally shared by other materials.

Monolithic buildings in béton, with arched ceilings in all the rooms, are practically fire-proof.

68. It may be advantageously used in fortifications, for foundations, generally, both in and out of water; for the piers, arches, and roof surfaces of casemates; for parade and breast-height walls; for counterscarp walls and galleries; for scarp

walls, except those that shield guns; for service and storage magazines; for pavements of magazines, casemates, galleries, &c., and generally for all masonry not exposed to the direct impact of an enemy's shot and shell.

Carefully laid on as a roof surface over arches, it is claimed that the usual covering of bituminous mastic may be dispensed with.

69. Its superiority to Rosendale concrete for common work, such as foundations, the backing and hearting of walls, magazine walls, and generally for all masonry protected by earth and therefore not necessarily required to be of first quality, lies in its possessing greater strength and hardness at the same cost, and consequently in its being proportionately cheaper when reduced to the same strength by increasing the proportion of sand.

COST.

70. The cost of works constructed in béton aggloméré will, of course, depend in a great measure on that of the lime and cement which enter into its composition.

In Paris, where Portland cement costs from \$9 to \$10 per ton in gold, hydraulic lime about half as much, and labor ranges from 60 cents to 70 cents per day, the béton of common quality will cost, inclusive of profit, from \$5 to \$6 per cubic yard in plain finished walls.

Arch work is more expensive, and where a variety of centres are required, and the arches groin into each other and rest on numerous columns, the cost of the finished work, which of course includes that of the centres and moulds, may reach as high as \$12 to \$13 per cubic yard.

APPLICATION AND COST IN THE UNITED STATES.

71. It has already been stated that neither Portland cement nor hydraulic lime suitable for béton aggloméré is manufactured in the United States. To import these materials and pay the duty costs about \$20 per net ton in gold for cement, and more than half as much for the lime.

At these rates béton of good quality, composed say of 5 measures of sand, one-half a measure of lime, and 1 measure of cement, can be manufactured in plain walls for from \$9 to \$11 per cubic yard for labor and materials alone, the cost varying with the height to which the béton has to be carried.

A common article can be made at the cost of ordinary brick masonry of equal strength, say from \$8 50 to \$9 per cubic yard,

with these advantages in favor of the béton, that a moderate degree of ornamentation, and any desired shade of color, from a light drab or fawn to a dark gray or brown, may be conferred at a trifling addition to the cost.

72. Bétons of average quality may be made with a matrix of hydraulic lime alone.

When great strength and hardness are required, the lime must be replaced, in part at least, by Portland cement, and the best results are attained with Portland cement alone.

In the French practice a compromise between the quality and the cost is effected by mixing the two matrices together in such proportions as the circumstances in each particular case may require.

The same object may be attained with a matrix of cement alone by varying the dose of sand, and observing the precaution, when large doses are used, to mix sands of different sizes together in order to reduce the volume of voids and diminish the porosity.

Which of these two methods will give the best low-priced béton aggloméré in process of time is a point of inquiry which has attracted very little attention, and is of no special importance where the cement and lime may both be readily procured without depending upon foreign markets. In the United States, however, the question rises into prominence, and a series of experiments is now in progress to determine it; for although we can manufacture good Portland cement, by the dry process, at a little more than half the cost of its importation, it is not known that we have any argillaceous limestone deposits suitable for hydraulic lime, and it is equally uncertain whether an artificial hydraulic lime will answer as well as the natural limes, of which those of Seilley and Theil may be taken as types.

It, however, stands to reason, and, in the absence of positive knowledge to the contrary, may be assumed as true that, having a Portland cement béton and a hydraulic lime béton of the same initial strength and hardness, their ultimate qualities in these respects, and their durability under severe climatic trials, will vary inversely as their porosity, within moderate limits of discrepancy. Exposed to the weather, in climates not visited by heavy frosts, they should remain equally good for an indefinite period. Immersed in sea water, the least porous of the two would be the least liable to change.

Common lime powder, freshly slaked by aspersion, may be added to a matrix of Portland cement in small proportions, say not greater than 1 of lime to 4 or 5 of cement by volume, without seriously impairing its strength, and with a great improvement in the texture of the béton.

When large doses of sand are used, the imperviousness to water of the béton, and also its strength, are increased by adding common lime powder, in proportions not greater than eight-tenths of the cement by volume.

It seems probable, from the experiments already made, that béton aggloméré for plain, cheap work, will be made in this manner in the United States, and that we will manufacture our own Portland cement, and dispense altogether with the use of hydraulic lime derived from argillaceous limestone.

73. It is of great importance that the incorporation of the lime with the cement should be very thorough, in order to insure a perfectly homogeneous mixture, and this can be obtained with greater certainty by triturating the two together into a thick, viscous paste before the sand is added. In conducting extensive operations the use of two mills of different sizes would perhaps be advantageous, the smaller one being employed exclusively in the preparation of the matrix.

The following proportions may be relied upon to give Coignet bétons of good average quality:

	1	2	3	4
Coarse and fine sand, by measure	6	$6\frac{1}{2}$	7	$7\frac{1}{2}$
Portland cement, by measure	1	1	1	1
Common lime powder, by measure	$\frac{4}{10}$	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{8}{10}$

74. For foundations and other plain massive work not exposed to view, or where a smooth surface is not specially desired, a liberal amount of gravel and pebbles, or broken stone, may be added to all of the bétons of the above table.

The following proportions will answer for such purposes:

	1	2	3	4
Coarse and fine sand, by measure	6	$6\frac{1}{2}$	7	$7\frac{1}{2}$
Gravel and pebbles, by measure	12	13	13	14
Portland cement, by measure	1	1	1	1
Common lime powder, by measure	$\frac{4}{10}$	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{8}{10}$

74 *a.* The following table (XVI) was not completed in time to take its proper place in this report, and is therefore inserted here. It gives the results of some of the trials that were made in determining the proportions recommended in the two foregoing paragraphs. Broken stone of various sizes, from that of a pea to that of a duck's egg, would give better results than the gravel and pebbles that were employed.

In Table XVI the blocks tested were two months old, and were exposed to the weather, through the months of December and January 1870–'71, upon the roof a building where the thermometer frequently reached as low as zero, Fahrenheit.

Their dimensions were $3\frac{1}{2}$ by $5\frac{1}{2}$ by 3 inches, the area under compression bring $19\frac{1}{4}$ square inches.

It will be seen that the blocks containing 13 volumes of the gravel and pebbles gave a greater average strength than those containing 5 volumes, the other ingredients in both cases being the same.

TABLE XVI.—(*From General Gilmore's experiments.*)

No.	Proportions of dry ingredients by volume, loosely measured.	Crushing strength, in pounds. Total.	Crushing strength, in pounds. Per square inch.
1	Boulogne Portland cement, 1; common lime powder, 0.4; sand, 5.6.	18,000 16,000	935 831
2	Boulogne Portland cement, 1; common lime powder, 0.8; sand, 5.6.	15,500 19,000	805 987
3	Boulogne Portland cement, 1; common lime powder, 0.4; sand, 7.5.	8,000 10,000	415½ 519
4	Boulogne Portland cement, 1; common lime powder, 0.8; sand, 7.5.	10,600 11,000	551 571
5	Boulogne Portland cement, 1; common lime powder, 0.4; sand, 5.6; gravel and pebbles, 5.	12,500 13,100	649 681
6	Boulogne Portland cement, 1; common lime powder, 0.4; sand, 5.6; gravel and pebbles, 13.	13,000 16,000	675 831
7	Boulogne Portland cement, 1; common lime powder, 0.8; sand, 5.6; gravel and pebbles, 5.	12,500 12,000	649 623
8	Boulogne Portland cement, 1; common lime powder, 0.8; sand, 5.6; gravel and pebbles, 13.	12,500 14,500	649 753

75. When the Archimedean screw-mixer is used, some difficulty will be experienced in incorporating the gravel and pebbles with the same machine, from the liability of its getting jammed in between the edge of the screw and cylindrical case in which it revolves. The trouble will not arise from either the

large or the small pebbles, but only from the medium sizes. The difficulty might be avoided by mixing with a pug mill suitably constructed, or by using two machines, one for incorporating the matrix with the sand, and the other a concrete mixer, for introducing the pebbles to the mixture thus obtained. For monolithic concrete work, in water, the lime should be omitted.

GENERAL OBSERVATIONS.

INCREASE OF STRENGTH OF BÉTON AGGLOMÉRÉ WITH AGE.

76. Bétons and mortars, in which the matrix is Portland cement alone, acquire, during the first two years, fully nine-tenths of the strength and hardness which they ultimately attain in process of time.

77. **Tensile strength.**—At the age of one month the tensile strength of Portland cement, without sand, is equal to about two-thirds of what it attains during the first two years.

When sand is added, the ratio of increase in tensile strength is greater than with the neat cement, sometimes reaching in two years, with the larger proportions of sand, as high as seven and eight times the strength acquired during the first month. With equal portions of cement and sand, the strength acquired in one month is about doubled at the end of two years.

The curves of the diagram, Plate I, although of less value, in consequence of having been derived from various authorities, than they would have been if made by one single experimenter, present a comprehensive view of this subject. The discrepancies which present themselves under a close comparison, are due to the use of cements of various qualities mixed under various conditions.

78. **Crushing strength.**—It is known that the strength of Portland cement mortars and bétons, to resist compression, does not reach its maximum limit within a period of two or perhaps three years. During the first month the compressive strength of neat cement per square inch, upon blocks about the size of ordinary burnt bricks, laid flatwise, is from seven to eight times the tensile strength per square inch of the same mixture. At the age of six months this ratio becomes about 12 to 1, and at nine months nearly 14 to 1.

When sand is added, the difference between the tensile and the crushing strength on the same unit of area is much greater than with cement alone, and increases with the amount of sand used.

With a mixture of cement 1 and sand 2, the ratio of the crushing to the tensile strength will generally be found between the limits of 14 to 1 and 19 to 1; with cement 1 and sand 4, it reaches as high as 25 to 1 and even 29 to 1; and with cement 1 and sand 5, as high as 35 to 1. These relations are maintained as a rule up to the age of nine months, beyond which period our information depends so much upon experiments made at different times and places, and by different persons, as to be in a measure impaired for practical use and application.

As a rule, the crushing strength of bétons, in which the matrix is Portland cement, at the age of three months, becomes nearly doubled at the age of nine months.

79. *a.* All possible mixtures of Portland or natural American cements, with or without sand, with much or little water, if arranged in the order of their strength at any time after they are five days old, will, as a rule, remain in that order throughout all subsequent induration.

80. American cements made from argillo-magnesian limestone at the following-named localities, when manufactured with care, do not differ greatly in quality, viz: Cumberland, Maryland; Louisville, Kentucky; Utica, Illinois; Coplay, Pennsylvania; Shepherdstown, Virginia; Round Top, near Hancock, Maryland; Akron, New York. They are, however, somewhat inferior to Rosendale cement of average quality.

81. The tensile strength of the best Portland cement, seven days old, is about six times as great as that of the best natural American cements, both being mixed without sand. About the same ratio exists between the medium grades, and also between the lower grades of these two classes of cements. This is true whether mixed with little water, like béton aggloméré, or with much, like masons' mortar.

82. A mixture of Portland cement and sand, in proportions suitable for mortar, seven days old, made with much or little water, possesses from four to six times the tensile strength of a mixture of Rosendale cement and sand in the same proportions, similarly treated.

83. The tensile strength of both Portland and Rosendale cements, with or without sand, is less when made plastic, like stiff masons' mortar, than when made simply damp and incoherent, like béton aggloméré. With Portland cement the differ-

ence is from 20 per cent. to 30 per cent., and with Rosendale cements much greater.

84. The tensile strength of the best neat Rosendale cement, seven days old, is more than twice as great as that of the poorest, and when mixed with three times its weight of sand, is as strong as the poorest without sand.

85. Neat Rosendale cement mixed with neat Portland cement is very little better than the same weight of sand, until the amount exceeds six times that of the Portland cement. This result is from mixtures seven days old, and is due to the fact that the adhesion of the Portland cement to the sand is about equal to the cohesive strength of the particles of Rosendale cement, until the amount of sand exceeds six times that of the Portland cement, when the adhesive strength of the sand mixture, in consequence of its porosity, falls below the cohesive strength of the two cements.

86. The crushing strength of neat Portland cement, seven days old, is not quite four times as great as that of neat Rosendale, both being mixed rather dry, and rammed. If both are made plastic, like mortar, the former is nearly twenty times as strong as the latter.

Mixed with different proportions of sand, like béton aggloméré, the crushing strength of Portland cement is from 6 to 12 times as great as Rosendale similarly treated, and from 16 to 19 times as great when both are made soft, like mortar.

87. The cost of Portland cement in New York, inclusive of custom-house duties, is about fifty per cent. greater than that of Rosendale cement, while for all the purposes to which cements are usually applied it is three times as valuable.

88. Any admixture of sand with either Portland or Rosendale cements diminishes both the tensile and crushing strength.

89. At the end of one year the tensile strength of Portland cement, mixed with an equal volume of sand, is about three-fourths of that of the neat cement. With two parts of sand, the strength is two-fifths that of the neat cement; with three parts, not quite one-third; with four parts, about one-fifth; while with five parts of sand, the strength lies between one-ninth and one-eighth that of neat cement.

90. Sea water is nearly as good as fresh water for mixing Portland cements, but injures the Rosendale, and all argillo-magnesian cements, very considerably.

91. In mixtures of Portland cement and sand for either

monolithic work or separate blocks, one-half the sand may be replaced advantageously by coarse pebbles, resulting in an increase of both the tensile and the crushing strength.

92. Neat Portland cement, mixed with $\frac{1}{8}$ to $\frac{1}{4}$ of its weight, or $\frac{4}{10}$ to $\frac{8}{10}$ of its volume of common lime powder, loosely measured, loses from $\frac{1}{3}$ to $\frac{2}{5}$ of its tensile strength. Mixed with $\frac{1}{2}$ its weight, or $1\frac{6}{10}$ its volume, it loses $\frac{3}{5}$ of its strength. Mixed with $\frac{3}{4}$ of its weight, or $2\frac{4}{10}$ its volume, it loses $\frac{2}{3}$ of its strength.

93. All Portland cement mixtures acquire greater strength and hardness immersed in water than if kept in the open air.

Concrete blocks, until required for use, should be wet daily, and shaded from the sun in warm weather. A good plan, when practicable, is to make them on the beach between tides, when they will be submerged twice a day.

94. Monolithic work of Portland cement concrete in water should not be made with the best or slowest-setting cement, but with one that is more active, and the water must be perfectly quiet. The method of manipulation and treatment is the same as for Rosendale cement concrete, but the proportion of sand and ballast may be twice as great.

95. Good Portland cement weighs not less than 109 pounds to the bushel, loosely measured, is of a blueish gray color, and requires from three to four hours to set. The inferior cements are lighter in weight, quicker setting, and of a brownish color. The inferiority may arise from the presence of too much clay, or from inadequate burning.

96. The use of béton aggloméré in France dates back to the year 1856, and confidence in its value has been constantly on the increase since that date.

THE MANUFACTURE OF MATERIALS FOR BÉTON AGGLOMÉRÉ.

97. The prominence given in the foregoing pages to a description of the characteristic properties of hydraulic lime and Portland cement (the two materials upon which béton aggloméré depends for its excellence) has been deemed necessary, in order that M. Coignet's processes of manufacture may be fully understood.

The practice in France and elsewhere, wherever this béton has been introduced, requires not only that the cementing material shall possess hydraulic energy, but that this energy shall be of the peculiar kind inherent in argillaceous limestones judi-

ciously burnt; shall be, in fact, derived from hydraulic lime and Portland cement, as already described.

It rejects the dolomite as a class, and all limestones largely dependent for their hydraulicity upon magnesia. It also rejects, for the reasons stated, a matrix of fat lime alone.

It seems proper that the method followed at the present day, for producing hydraulic lime and Portland cement on a large scale, in order to meet the great and increasing demand for them, should now be briefly described. Nothing but a general outline of the processes in most successful use will be given.

MANUFACTURE OF HYDRAULIC LIME.

98. In France, the practice of using lime that has been slaked in large bulk to a state of paste, by a copious use of water, has been entirely discontinued within the last few years, for the reason that only the fat or feebly hydraulic limes can be so treated.

The presence of a sufficient amount of clay to confer eminently hydraulic properties upon the lime, engenders the presence of lumps and portions not susceptible of thorough extinction by the ordinary means, which would not only render the mortar heterogeneous, but might endanger the stability and safety of the masonry, by subsequent slaking within the work.

Hence, whenever the advantage of employing hydraulic lime, either alone or mixed with cement, in order to confer energy and strength upon mortar, has been recognized, the lime is invariably used in a state of freshly slaked, impalpable powder. The use of fat lime has been very generally discontinued upon important works.

99. The following method is the one commonly practiced for obtaining hydraulic lime from argillaceous limestones containing from 12 to 24 per cent. of clay, the latter being composed of about 2 of silica to 1 of alumina.

The stone is burned in any suitable kiln, at a heat sufficient to expel all the carbonic acid gas.

There is no advantage in a high heat, like that necessary for burning Portland cement.

While still warm from the kiln, the stone is sprinkled with from 15 to 20 per cent. of its own weight of water, care being taken not to use enough to convert any portion of it into paste. The slaking soon begins, and the stone falls to pieces, a portion

of it in the condition of fine powder, while the rest remains in unslaked, or partially slaked, lumps of various sizes.

The whole mass is then thrown together in large heaps, where it remains undisturbed for six or eight days, in order to complete the extinction as far as possible, and is then screened with a sieve of twenty-five to thirty fine wires to the lineal inch.

The portion which passes the screen is hydraulic lime of first quality, if the stone be capable of yielding such, and, when used, requires only sufficient water to convert it into a stiff paste, in order to furnish an excellent matrix for mortar, béton, or concrete.

The lumpy portions which do not pass the sieve either contain too much clay, or have been burnt at too high or too low a heat to be susceptible of thorough extinction by exposure to the air, or aspersion with water. The quantity of this lumpy residue will be great in proportion to the amount of clay in the stone, or the extent to which the heat in burning has been improperly regulated.

In some localities this residue is thrown away, as dangerous or worthless, while in others it is the custom to grind it up separately, and mix it with the powder previously obtained by aspersion.

When the burning has taken place at a heat suitable for making common lime, the residue owes its origin to the presence of clay, and may be a light, quick-setting cement, like the Roman.

If so, its incorporation with the lime powder will augment the hydraulic activity of the latter, though perhaps not its ultimate strength and hardness.

When the residue is too much under-burnt to slake readily, it may cause damage by a tardy extinction in the mortar, and should be rejected.

When burnt at a high heat, the residue may be Portland cement, if the stone contain from 20 to 22 per cent. of clay; or it may be inert clinker, partially or wholly vitrified, depending not only upon the amount, but also upon the form in which the silica and alumina exist in the clay.

The character of the residue, when ascertained, will determine whether it would be advantageous or otherwise to add it to the lime powder produced by slaking.

For these reasons the utilization of the unslaked lumps obtained in the manufacture of hydraulic lime requires constant

and watchful care, in order that the introduction of ingredients that are worthless, or perhaps both dangerous and worthless, may be avoided.

MANUFACTURE OF HYDRAULIC LIME AND PORTLAND CEMENT AT ONE BURNING.

100. M. Coignet has devised a method for making both hydraulic and Portland cement, at one and the same burning, from heterogeneous argillo-calcareous limestone, in which the proportion of clay may vary irregularly from 10 to 30 per cent.

Incidentally a third product (a cement inferior to the Portland, and resembling the Roman and the Rosendale varieties) results from this process.

The following is a condensed description of this new method:

84. The *hydraulic lime*, of which the process of manufacture is here described, is not similar to the article of the same name made in Austria, by burning limestones containing so large an amount of clay (generally exceeding 20 per cent.) that they cannot be slaked by aspersion with water after burning, but must be reduced to powder by grinding.

The Coignet process applies to hydraulic lime derived from stone containing less than 21 to 22 per cent. of clay, which, after leaving the kiln, is slaked to powder by sprinkling with water.

By the usual mode described in paragraph 99, the burnt lime, after being sprinkled with water, is first formed into heaps to facilitate the slaking, and is subsequently screened through fine wire-cloth, the portion which passes the screen being hydraulic lime.

In operating with lime rich in clay, the unslaked, lumpy residue, rejected by the screen, is frequently so large a proportion of the whole as to be a source of serious loss to the manufacturers if thrown away, while, as already stated, all attempts to incorporate it with the powder obtained by slaking and screening are attended with danger.

By the new method, the lumpy portions which accumulate at each screening, instead of being ground and added to the lime powder, are, after being ground, mixed with freshly-burnt stone just before the latter is watered for slaking, so that they are again exposed to the heat and vapor developed by the slaking process. By this device those portions which would, by the usual treatment, have been liable to subsequent deleterious

action when made into mortar, become thoroughly reduced, and their presence becomes a benefit instead of an injury to the masonry into which they enter, by augmenting its strength and hardness. Indeed, the greater the amount of residue thus treated, the greater will be the hydraulicity, and consequently the value, of the resulting product.

101. This manner of treating the pulverized residues arising in the manufacture of hydraulic lime, is one of the peculiarities of the new process. Another consists in producing, at the same burning, heavy, slow-setting Portland cement, as hereinafter described.

102. Hydraulic cements owe their peculiar properties to a combination, under the influence of heat, of a certain quantity of clay with oxide of calcium, producing double silicates of lime and alumina.

103. Experience has shown that the proportion existing between the clay and the lime exercises a controlling influence, not only on the results obtained in burning, but on the practical manipulation subsequent thereto, in order that the maximum hydraulic energy, as regards both intensity and permanence, may be secured, and the danger of tardy action in the body of the mortar lessened or avoided.

In fact, when an argillaceous limestone does not contain at least 20 per cent. of clay, the lime is in excess, and no useful purpose can be subserved by exposing the stone to an excessive heat, inasmuch as the semi-fusion so characteristic of cement will not ensue, or, if apparently produced, the cement, when ground and tempered with water, will be unstable. It may, in fact, fall to pieces from the spontaneous slaking of the excess of quicklime present, this excess being the portion which has not been converted during the calcination into silicate or aluminate of lime.

If, on the other hand, the limestone contains more than 22 to 23 per cent. of clay, it fuses at a moderate heat, and becomes a kind of glass, destitute of useful hydraulic energy, and liable to disintegrate and fall to powder while cooling in contact with the air.

If the temperature be kept so low that the stone containing more than 23 per cent. of clay will not vitrify, it yields a cement of greatly inferior energy, and liable to soften when made into mortar and exposed to moisture; while, under the same moderate heat, those portions containing 20 to 22 per cent.

of clay, and therefore suitable for Portland cement, leaves the kiln as a light, quick-setting underburnt cement, or hydraulic lime, possessing not more than one-fourth to one-third of the intrinsic value of the Portland cement of average quality.

104. These light, quick-setting cements are also produced by a moderate burning, from stone containing as high as 27 per cent., or even 30 per cent., of clay. Indeed, the amount of clay may reach, exceptionally, as high as 35 per cent.

The cement made at Vassy, in France, the English and French Roman cements, and all of the American cements, (the Rosendale, Shepherdstown, Cumberland, Coplay, and others,) belong to this class.

In Austria the name of hydraulic lime is given to cements of this description.

The Roman cement, made from the nodules of septaria derived from the Kimmeridge and London clay, is the best of the cements here referred to, though greatly inferior in strength and hardness to the Portland.

105. Experience has fully proved that the heavy, slow-setting cements (the class upon which the name of Portland has been conferred, from the resemblance of the English variety to natural Portland limestone) can only be obtained by burning, at a high heat, either limestones containing at least 20 and not more than 22 per cent. of clay, or an artificial mixture of the ingredients in similar proportions.

Natural stone, suitable for this purpose, is found in Europe in the first range of the Jura formation, and on the lower slopes of the Alps in France and Austria. It generally occurs in numerous layers, which are very variable in the amount of clay which they severally contain, not exceeding from 10 to 15 per cent. in some, and reaching as high as 20, 25, and even 30 per cent. in others. The layers are generally thin, and there are but very few of them in which the desired proportion of 20 to 22 per cent. of clay exists, homogeneously distributed. By far the greater number contain either less or more than this amount.

In whatever manner apparently homogeneous limestones may be exposed to burning, at a high temperature, it is impossible to avoid the complete vitrification of some layers containing too much clay, while others, not containing enough, or less than 20 to 22 per cent., produce cements having lime in excess. These are all more or less liable to the danger of tardy slaking, already referred to. So great and so common is this danger,

indeed, that an artificial mixture of clay and carbonate of lime has been very generally relied upon for Portland cement.

HYDRAULIC LIME AND PORTLAND CEMENT OF SEILLEY, FRANCE.

106. The argillo-calcareous deposit of Seilley, from which both hydraulic lime and Portland cement are manufactured by Mr. Coignet's method, for the *Société Centrale des Bétons Agglomérés* of Paris, is of this heterogeneous character, comprising more than one hundred layers of stone, of very variable composition. Among these different layers the amount of clay varies from 12 to 25 per cent.

In a thickness of eighty feet, comprising the useful working portion of the quarry, there is an aggregate of about twenty-five to thirty feet of practically homogeneous stone, containing from 20 to 23 per cent. of clay, and therefore suitable for Portland cement. To select and set aside these layers only, many of which are not more than four or five inches in thickness, would be impracticable. There would always be mixed up with the selected stone, some portion containing too much, and others containing too little clay for Portland cement.

That part of the burnt product which resisted extinction by the ordinary process of sprinkling, and therefore comprising all the cement, would also contain a notable percentage of unslaked hydraulic lime.

The method devised for overcoming these difficulties consists, as already stated, in mixing the pulverized lumpy residue with freshly-burnt stone, and again subjecting it to the heat and vapor developed in slaking. By this means the superior energy of the residue is utilized as far as possible, the maximum quality of hydraulic lime which the stone is capable of yielding is obtained, and all danger of disintegration from ulterior slaking is avoided.

107. It is to be borne in mind that Portland cement can only be made from a mixture, natural or artificial, of 20 to 22 per cent. of clay and 80 to 78 per cent. of carbonate of lime, and that the calcination must take place at a temperature sufficiently high to produce that peculiar softening which precedes incipient vitrification, it being at this stage alone that those silicates, upon the crystallization of which, in the presence of water, this cement depends for its peculiar merits, can be formed.

108. In applying this method in practice, the entire product of the quarry is burnt with a heat of sufficient intensity and duration to convert those portions, containing 20 to 22 per cent. of clay, into Portland cement. The results are as follows:

1. The stone containing more than 22 per cent. of clay would be more or less thoroughly vitrified, and would fall to powder upon cooling in the air, and could therefore be readily separated from the rest.

2. The stone containing less than 20 per cent. of clay, being the most refractory of any in the kiln, would remain in the condition of lime, more or less hydraulic, and easy of recognition and separation, in the manner hereinafter described.

3. The stone containing 20 to 22 per cent. of clay would be Portland cement *clinker*, requiring only to be pulverized by grinding, to complete the process of manufacture.

Upon this entire product of the kiln, mixed together, enough water is sprinkled to effect the slaking of the lime, and it is then formed into heaps and allowed to remain until all portions capable of thorough extinction by the heat and vapor developed, that is, all the hydraulic lime, fall into powder. The portion which resists slaking is Portland cement.

The two are separated by screening, and the cement is reduced to powder by grinding.

In practice it will be found that there are some lumpy portions of the slaked heaps, which, although they do not pass through the screen, are nevertheless not Portland cement. They result from the imperfect calcination of stone containing between 18 and 20 per cent. of clay, lying between the limes that slake entirely to powder, and the cements that do not slake at all. They are slaked, indeed, but not to powder, and there is no danger of any ulterior disturbance from them. The lumps are quite soft, entirely unlike the cement, and require but little power to reduce them to powder. They are pulverized by passing the entire residue through a mill, having the stones slightly separated from each other, so that they are reduced by a kind of rolling motion which does not crush the Portland cement. The two are separated by a fine wire screen; the powder thus obtained being a light, slow-setting cement, weighing 78 to 80 pounds to the bushel; while the Portland cement, produced at the same time, weighs 98 to 101 pounds to the bushel.

109. It is claimed that this method of treating the entire yield

of a heterogeneous argillo-calcareous deposit, by burning it with that degree of heat required for converting into Portland cement those portions containing 20 to 22 per cent. of clay, really improves the quality of the hydraulic lime furnished by those portions containing less clay. There is no doubt that its weight is augmented, but, on the other hand, it is slightly adulterated with the dust of the vitrified stone, to which, indeed, its increased weight may be in part due. It is doubtless a good stable hydraulic lime. It is extensively used in the vicinity of Paris, and considerable quantities have been recently imported from the Seilley works into the United States, where it has given entire satisfaction.

110. This method of manufacture, applied to the entire yield of the quarry at Seilley, produces—

First. Sixty per cent. of excellent hydraulic lime, weighing, uncompacted, 50 to 55 pounds to the bushel, and which, mixed into a paste with water, will set in 10 to 15 hours, and sustain a wire point one-twenty-fourth of an inch in diameter, loaded to two pounds, in 20 to 24 hours.

Second. Ten per cent. of light, slow-setting cement, weighing, when not shaken down, 78 to 80 pounds to the bushel, that will sustain the same test in 8 hours.

Third. Thirty per cent. of heavy, slow-setting Portland cement, weighing, when not compacted by shaking or otherwise, 98 to 101 pounds to the bushel, that will bear the needle test in 4 hours.

111. It does not appear to be necessary at Seilley to repeat the slaking process upon any of the pulverized lumpy residue, by mixing it with freshly-burnt stone; but that the entire product of the quarry is converted, by one burning and one slaking, judiciously conducted, into one or another of these three materials.

112. The only works besides those at Seilley, where Portland cement is manufactured from a natural deposit, are located at Boulogne-Sur-Mer. A calcareous layer of the Kimmeridge clay, excavated with pick and shovel, furnishes the material.

A description of the process used at Boulogne is given in Gillmore's Treatise on Limes, &c., paragraphs 87 to 94.

Some changes have been made there, however, in the practice, so that at the present time the *wet process*, used in making artificial Portland cement in England, is the one followed at Boulogne.

ARTIFICIAL PORTLAND CEMENT.

113. Fully nineteen-twentieths of all the Portland cement made at the present day is artificial. In its manufacture, either the *wet process* of England, used also in making the natural Boulogne Portland, or the *dry process* of Germany, may be followed. A brief and very general description of these two processes is given below.

THE WET PROCESS.

114. The works in the vicinity of London employ both the white and the gray chalks of that neighborhood. Exclusive of the flint contained in them they are nearly pure carbonate of lime.

The clay is procured from the shores of the Medway and Thames, and the adjoining marshes and inlets. It contains about two parts of silica to one of all the other ingredients, comprising alumina, oxide of iron, soda and kali, carbonate of lime, &c.

First. The clay and the chalk are mixed together in the proportion of about 1 to 3 by weight, in a circular wash mill, provided with heavy harrows revolving on a vertical shaft, to secure the perfect reduction of the particles of chalk to an impalpable paste. The chalk is not allowed to mingle with the clay until it has passed a fine wire sieve.

Second. When a thorough mixture is thus effected, the liquid, resembling whitewash in appearance, is conducted to large open reservoirs called backs, where it is left to settle. The clear water, as it rises to the surface or the heavier materials subside, is drained off. A portion of that which remains mingled with the raw cement goes off by evaporation.

During the time the mixture remains in the backs, samples are taken of it constantly and made into cement in sample kilns, to test the accuracy of the proportions. If any error in this respect is discovered, it is corrected by new material washed into the backs, or by mixing together the contents of two or more backs.

The time required for the contents of the backs to obtain sufficient solidity to bear transportation to the drying stoves varies with the wetness or dryness of the season.

Third. When the raw cement mixture has attained the consistency of butter, it is taken out of the backs by shovelfulls,

like stiff mud, and, in that form and condition, is removed to stoves heated by flues, and dried.

Fourth. After being dried—although it is not necessary to expel all the moisture—it is burnt with gas coke in perpetual bell-shaped kilns, which are fed daily from above and drawn below.

The coke and raw cement are put into the kiln in alternate layers, in the proportion of about one part by weight of coke to two of cement, and the burning must be carried to the point of incipient vitrification.

When properly burnt the pieces of cement called clinker, are of a greenish color, and are cracked, contorted, and much shrunken from the effects of the heat.

Fifth. The cement clinker is ground between millstones to that degree of fineness that when passed through a No. 30 wire sieve, of 36 wires to the lineal inch, there shall not be a residue exceeding 10 per cent.

Sixth. The cement powder poured into a measure, and not compacted by shaking or otherwise, should weigh not less than 106 pounds to the struck English bushel. Some engineers exact 110 pounds per bushel.

Seventh. Made into a stiff paste without sand, and immersed in water within twenty-four hours thereafter, the sample, when seven days old, should sustain a tensile strain, varying with the different uses to which it is to be put, of from 178 to 222 pounds to the sectional area of one inch. Few cements weighing less than 100 pounds to the loose bushel will sustain this test.

THE DRY PROCESS.

115. By this process any of the compact limestones, as well as the chalks and marls, may be employed for Portland cement. It is well to remember in practice, however, that the consumption of power required to reduce the hard carbonates to powder, places them under a great disadvantage in neighborhoods where chalk or soft marl abounds.

First. The raw materials — both carbonate and clay — are kiln-dried at 212° Fahrenheit, in order to expel the moisture and prevent caking in the mill, and otherwise facilitate grinding and sifting.

Second. After drying, the clay and carbonate of lime are mixed together in suitable proportions and reduced to a fine powder. In most localities the proportion will be between

the limits of 20 to 23 per cent. of clay, to 80 to 77 of the carbonate.

One kind of machine will not suffice for grinding the raw materials economically.

In the German manufactories three are used, viz:

First. A stone-breaking machine, of the kind usually employed for breaking stone for roadways, or for concrete. Through this the dried and mixed materials are passed, issuing therefrom in pieces not exceeding the size of a walnut.

Second. A further reduction is effected by a vertical mill or edge runners.

Third. The material is ground between horizontal millstones to a powder of such degree of fineness that 90 per cent. of it should pass a wire screen of eighty wires to the lineal inch.

Third. The powdered material is then formed into a rather stiff paste in a brick-making machine, and made into bricks of suitable size for burning. During this operation there is an advantage in keeping the mixture warm, which may be done by coils of steam pipes or otherwise.

The liquid which is added to the powder in the brick machine to form the paste is made by adding to 100 pounds of water, $2\frac{1}{4}$ to 6 pounds of calcined soda, and 5 or 6 pounds of newly burnt slaked chalk or lime. This mixture is kept hot in a sheet-iron vat containing a coil of steam pipe in the bottom. It is kept thoroughly mixed by a revolving vertical shaft with horizontal arms. One hundred parts of the raw powder requires from 30 to 35 parts of this liquid.

Fourth. The bricks are dried by artificial means, and are then burnt at a high heat and ground to a fine powder, as in the wet process.

The same number of mills are necessary for grinding the cement, as are used in pulverizing the raw materials. The clinker is first put into a stone-breaking machine, then into a vertical mill, and, lastly, is ground to an impalpable powder in a horizontal mill.

116. In the largest and best-managed manufactories of Portland cement in Europe, in which none but a first-class article is produced, there is always a competent chemist employed to make daily trials of the materials on a small scale, in order that any departure, however slight, from the best proportions of the ingredients, may be averted before it can occasion any serious injury to the average quality of aggregate yield. An

active competition in the business has rendered it necessary to leave nothing to the results of chance.

KILNS FOR BURNING PORTLAND CEMENT.

117. The most difficult part in the operation of making Portland cement, by either process, is the proper application and management of the heat in burning. It is an easy matter to pulverize and mix the raw materials when either wet or dry, and to grind the burnt stone to a fine powder. But the mysterious conversion which takes place in the kiln, under a heat of sufficient intensity to make glass, is to a great extent beyond our knowledge, and to some extent beyond our control.

118. All the manufactories in Germany, with one or perhaps two exceptions, burn the cement in intermittent kilns, which are about 50 feet high and 10 feet in greatest diameter. The kiln is filled with alternate layers of raw cement and coke, or coal, and then fired. About three days are required for the burning, and from five to eight days for the kiln to cool off so that it can be drawn. These kilns, judged by the quality and quantity of their yield, are the most expensive kind that can be used. They are no improvement upon those in use one hundred years ago, and require the most skillful management and supervision to produce even moderately fair results.

119. The perpetual bell-shaped kilns used in England and at Boulogne, although superior to the intermittent German kilns, fall far short of satisfying the essential conditions of a good kiln. They consume too much fuel, the control of the combustion is attended with considerable difficulty, and the results are liable to be to some extent uncertain.

THE ANNULAR KILN.

120. The annular or ring kiln, in which the burning chamber is placed around the circumference of a circle, ellipse, or oval, is doubtless, in one form or another of its several modifications, the best that has been yet devised for burning either cement, lime, or bricks.

121. *The Hoffmann kiln*, considered as a type of this class, is not, perhaps, inferior to any of the others, and will be briefly described. (See Plate IX.)

DESCRIPTION OF THE HOFFMANN KILN.

122. Imagine a railway tunnel, 8 to 9 feet high, by 10 to 12 feet span, constructed round a circle or an oval of such dimen-

sions that, measuring round the middle line of the annular chamber thus formed, the periphery is about 350 feet. This annular tunnel is called the burning chamber. In the centre of the space enclosed by the ring, is a long chamber called the smoke chamber, leading to a chimney 140 to 150 feet in height. This chimney may stand within the central space, or exterior to it. In the latter case a smoke flue would lead from the smoke chamber, under the burning chamber, to the base of the chimney. Fourteen radial flues, at equal intervals, lead from the burning chamber to the smoke chamber, each provided with a bell-shaped damper, which may be opened or closed, as required. There are fourteen doorways through the outer wall of the burning chamber, each 5 feet in height by 4 feet wide, placed at regular intervals. The arched top of the burning chamber is pierced at intervals of 3 to 4 feet, with holes about 5 inches in diameter, called the feed holes, which are used for supplying the fires with fuel. There are about 300 of them, each closed with a bell-shaped cover fitting over a rim or curb, and dipping into sand.

The whole should be substantially built of stone or brick masonry, and covered with a permanent roof.

The burning chamber should be lined with fire-bricks when the kiln is intended for burning cement.

123. **Manner of using the kiln.**—Let the doorways be numbered from 1 to 14, counting from left to right as you enter a doorway, and let the fourteen flues be numbered in the same manner.

When the kiln is in operation, all the doorways but two, or exceptionally three, are kept closed with temporary brick-work. Suppose only 1 and 2 to be open. Workmen are engaged in taking burnt lime from doorway No. 2, and others in conveying raw limestone in at doorway No. 1, and piling it up in the burning chamber, leaving vertical openings under the feed holes and horizontal passages for draught, parallel to the periphery.

It is convenient to call each portion of the burning chamber between two consecutive doorways a compartment, although there is no permanent division of the burning chamber into smaller chambers.

When the kiln is in operation, usually all the compartments but two are filled with cement stone, in all stages from raw stone to thoroughly burned cement. Suppose compartments 1 and 2 empty, and all the others filled. No. 3 contains cement

from stone put in 12 days ago; No. 4 that from stone put in 11 days ago; and so on around to compartment 14, which was filled yesterday. Separating No. 14 from No. 1 is a sheet-iron partition, as nearly as possible air-tight. This partition, called the *cut-off*, is movable. Yesterday it was between 13 and 14; to-morrow it will be between 1 and 2, and so on, being moved on one compartment each day. All the dampers are closed to-day except No. 14; yesterday all were closed except No. 13; to-morrow only No. 1 will be open. To-day men are removing burnt cement from compartment No. 2, and others are setting raw stone in compartment No. 1. Yesterday they were setting stone in No. 14, and removing cement from No. 1. To-morrow they will be removing cement from No. 3, and filling No. 2 with raw stone; so that every day the setting, drawing, cut-off, and open damper advance one compartment. The fires are in the centre of the mass, from the burnt cement end round to the raw stone end; say in compartments 7 and 8 to-day, 6 and 7 yesterday, 8 and 9 to-morrow, advancing one compartment per day, like the drawing and setting.

The compartment that was in fire yesterday, say No. 6, is still very hot to-day, No. 5 less hot, No. 4 cooler, and so on to No. 2, where the cement is cool enough to be handled, and men are removing it from the kiln, wheelbarrows, or trucks on portable railway tracks, being used for the purpose.

The compartments not yet fired are heated by the hot gases passing through them to the chimney, the stone in the compartment next the fire being at a full red heat, while that farthest off, which was put in yesterday, is only warm.

The draught of the chimney is sufficient to draw air in at the open doorways, through the entire mass of cement and raw stone, to the open flue, which is the one by the cut-off.

In passing through the burnt cement, the air takes up the residue of heat and becomes hotter and hotter, till, after passing through the cement burned yesterday, the hot current ignites at once the dust coal as it falls from the feed pipes, and the gases thus formed being carried on, mixed with air, it is probable the stone is burned considerably in advance of where the coal is supplied.

As the hot gases of combustion pass on, they give up their heat to the limestone, till, on arriving at the chimney, there is only heat enough remaining to cause a draught in a well-constructed chimney 140 to 150 feet in height. It is plain that *all* the heat

of combustion is utilized, except such as may escape through the walls of the kiln, and as the masonry is very massive, the loss from this cause is very slight.

124. One peculiar feature of these kilns is, that although less likely to get out of order than other kilns, from the fact that there is no movement in the burning mass, repairs may be easily made without letting the fire go down.

There are Hoffman kilns in which the fires have not been extinguished for five years.

One like that above described, operating at Llandulas, Wales, produces about 80 tons or 650 barrels of common lime per day, at a cost of 5*s.*, or $1 25 gold, per ton—estimating the unquarried limestone as of no value—as follows:

	s.	*d.*
Getting stone, including tools	1	3
Setting	0	5
Drawing	0	3½
Burners' wages	0	3½
Fuel, at 7*s.* per ton	1	6
Cost of producing lime	3	9
To which is added 33 per cent. for all expenses of management, &c.	1	3
	5	0

Making entire cost per ton 5*s.*, or $1 25 gold.

The lime sells at the works for 7*s.* per ton, ($1 75 gold.) The work is generally done by the ton, and at the above prices the men make from 3*s.* to 4*s.* (75 cents to $1 gold) per day.

125. At Mexham, near Chester, England, the cost of producing lime is the same as the above.

126. At Settle, in Yorkshire, where there is a Hoffmann kiln of about the same size, the setting, including running in the loaded trucks and running out the empty ones, costs sixpence per ton of lime, the drawing twopence per ton, the men earning from 3*s.* to 3*s.* 6*d.* per day.

127. At the current prices of labor and fuel in the United States, lime could be manufactured in a Hoffmann kiln at about $2 per ton, or between one-fourth and one-fifth of its present cost to consumers.

The details of cost may be liberally stated as follows:

Cost of quarry and plant $20,000.
Annual yield of kiln 20,000 tons.

	Cost per ton.
Interest on investment	$0 07
Quarrying	65
Setting in kiln	20
Drawing	15
Burners' wages	15
Fuel	43
Contingent expenses, 20 per cent	33
Cost of making one ton of lime	1 98

128. At Bieberich, on the Rhine, a Hoffmann kiln is used for burning artificial Portland cement. The quantity of fuel consumed is 77 pounds to the cask of 410 pounds. The cement is of excellent quality. There is no chalk in the neighborhood, and hard limestone has to be used in its stead.

129. The cost of manufacturing Portland cement in Germany, all contingent expenses included, generally varies from $6 60 to $6 70 (gold) per gross ton, and it is sold at a net profit of 40 per cent. on the outlay.

130. In the United States the cost would not vary greatly from $10 per gross ton, the works being located at the point of supply of the limestone, as follows:

Estimated cost of making Portland cement in the United States by the dry process, using hard limestone and a Hoffmann kiln.

Annual capacity of works, 30,000 barrels, or 6,000 tons.

Interest on $40,000 investment	$2, 800
9,000 tons raw limestone, delivered, at $1 50	13, 500
2,800 tons clay, at $1 40	3, 920
1, 100 tons pea and dust coal, at $4 30	4, 730
Salary of superintendent	2, 000
Salary of foreman	1, 200
Thirty-eight laborers, at $45 per month, average	20, 520
Two burners, at $75 per month	1, 800
Contingencies and wear and tear, 20 per cent. on above, except the interest	9, 534
Total cost of manufacturing 6,000 tons	60, 004
Cost of manufacturing one ton	$10

This estimate is believed to be a liberal one. It shows that Portland cement can be manufactured in this country at a cost less by from 12 to 14 per cent. than the wholesale market price of Rosendale, omitting the cost of barrels in both cases.

The Portland cement weighs 410 pounds and the Rosendale 310 pounds to the barrel.

131. There are nearly six hundred Hoffmann kilns in operation in Europe, varying in size from the one above described, capable of producing 20,000 tons of lime per annum, to kilns of one-eighth or even one-tenth of this capacity. Whether used for burning cement, lime, or brick, they give equal satisfaction, in respect to ease of management, economy of fuel, and uniformity of results.

RANSOME'S PATENT SILICIOUS CONCRETE STONE.

132. The process for making this stone followed at the present day was patented by Mr. Frederick Ransome, of London, in the year 1856. It rests upon sound scientific principles, and in practice consists in forming in the interstices of sand, or any pulverized stone, a hard and insoluble cementing substance or matrix, by the mutual decomposition of two chemical compounds in solution.

The compounds employed are: Silicate of soda ("soluble glass," "liquor of flints," "flint soap"), and chloride of calcium.

These when mixed together form, almost instantaneously, by mutual or double decomposition: Silicate of lime, and chloride of sodium (common salt).

133. The value of the artificial stone thus produced depends upon the strength, hardness, and durability of the silicate of lime which binds the sand together.

This is one of the compounds always formed during the setting of hydraulic limes and cements derived from the argillaceous and argillo-magnesian limestones, and upon which they largely depend for their value.

134. The process followed in manufacturing Ransome's stone, although attended by considerable labor, is exceedingly simple in theory. The raw materials employed are principally sand, gravel, flints, chalk, limestone, caustic soda, chloride of calcium and water. The sand may be coarse or fine, or a mixture of both, depending on the fineness of texture aimed at. Powdered chalk or limestone is generally mixed with the sand when a smooth surface and fine grain are required. The silicate of soda, or "flint soap," is made by boiling and dissolving flints in a strong solution of caustic soda under pressure.

In order to secure the best results, as well as for convenience

of manipulation, it should be of the consistency of molasses, although more tenacious, and possess a specific gravity of about 1.7. To every bushel of sand about one gallon of the prepared silicate of soda is added, and the whole mass is then thoroughly mixed together in a mill, until it attains a putty-like semi-plastic condition, fit for ramming or compacting into moulds.

With a suitable mill the mixing of each charge or batch requires but four or five minutes.

The prepared material is then pressed into moulds of wood or metal, by suitable implements, or it may be rolled into slabs, when that form is required, as for roofs, pavements, etc. The slab as soon as formed, and before the process proceeds further, may be cut into pieces of any shape that shall adapt it to the use to which it is to be applied.

When the material is once formed in moulds, it may be taken out immediately, and is not liable to warp or crack, or undergo any subsequent change of form.

The moulded blocks are at once drenched with a solution of cold chloride of calcium, which acts rapidly upon the silicate of soda, and hardens and solidifies the mass to that degree that it can be removed and handled without danger of breaking, during the subsequent steps of the process. They are then conveyed into cisterns containing a solution of chloride of calcium of about 1.4 specific gravity, and a temperature of about 212° Fahr. In this bath the chemical action is completed, and results in the formation of an insoluble silicate of lime through the mass, enveloping and cementing together the particles of sand, gravel, powdered limestone, etc., of which the block is composed. After the blocks have been saturated with the hot chloride of calcium, the completion of the process consists in washing away the chloride of sodium or common salt, evolved by the combination of the sodium with the chlorine. This is accomplished by thoroughly drenching the blocks with cold water for a longer or shorter time, depending on their size. The work is then finished and the block ready for immediate use.

135. An essential condition of success is, that the bath of hot chloride of calcium shall be applied while the silicate is still moist, or, in other words, as soon as the material is moulded into form. When thus applied, the double decomposition takes place, nearly, if not quite uniformly, throughout the entire mass. The blocks may be as large as can be conveniently handled. Were the moulded blocks allowed to dry before the application of the

chloride, the pores at the surface would be closed with silicate of lime, and the further penetration of the solution thereby impeded.

136. It would appear impossible, in the absence of positive knowledge to the contrary, that the chloride of sodium could be washed out from the interior of larged-sized blocks, by the most thorough and prolonged drenching with water; and admitting such result to be attainable, it would seem to prove the stone to be exceedingly porous. In practice, however, it has been found that the water does seek outlet, and carry off nearly all the salt in the form of brine, and that the stone becomes, in a few hours, as nearly impermeable to water as most of the varieties of natural sandstones.

PROPERTIES OF RANSOME'S SILICIOUS STONE.

137. The porosity and the percentage of degradation from various causes, of the Ransome stone, and of several natural building stones, were ascertained in 1861 by Dr. Edward Frankland, F. R. S., &c., &c., Professor of Chemistry at the Royal Institution, London. The specimens of the Ransome stone experimented on were two weeks old.

The following is extracted from Dr. Frankland's report, dated December 21, 1861:

"I have submitted to experimental investigation samples of stone forwarded to this laboratory, and have now to report as follows:

"The experiments were made in the following manner: The samples were cut as nearly as possible of the same size and shape, and were well brushed with a hard brush. Each sample was then thoroughly dried at 212°, weighed, partially immersed in water until saturated, and again weighed; the porosity or absorptive power of the stone was thus determined.

"The sample was then boiled with water until all acid was removed, and again weighed. Finally it was dried at 212°, brushed with a hard brush, and the total degradation or loss since the first brushing was ascertained. The following numbers were obtained:

Name of Stone.	Porosity—Percentage of water absorbed by dry stone.	Percentage alteration in weight by immersion in dilute acid. Of 1 per cent. acid. Loss.	Of 1 per cent. acid. Gain.	Of 2 per cent. acid. Loss.	Of 2 per cent. acid. Gain.	Of 4 per cent. acid. Loss.	Of 4 per cent. acid. Gain.	Total percentage loss by action of acid and subsequent boiling in water.	Further loss by brushing.	Total degradation from all causes.
Bath	11.57	1.28	..	2.82	..	2.05	..	5.91	.26	6.17
Caen	9.86	2.13	..	4.80	..	.67	..	11.73	1.60	13.33
Aubigny	4.15	1.18	..	4.00	..	..	1 04	3.56	.29	3.85
Portland........	8.86	1.60	..	1.10	..	1.35	..	3.94	.24	4.18
Auston	6.09	3 52	..	3.39	..	3.11	..	11.11	.27	11.38
Whitby.........	8.41	1.07	..	..	.53	None.	None.	1.25	.18	1.48
Hare Hill.......	4.31	.75	..	..	.60	None.	None.	.98	.15	1.13
Park Spring ...	4.15	.71	..	..	.10	.15	..	.81	None.	.81
Ransome'sPatent	6.53	..	.95	None.	None.	None.	None.	.63	.31	.94

The results furnished by the foregoing table are so easy of interpretation, that Dr. Frankland's remarks thereon are omitted. Dr. Charles T. Jackson, State Assayer of Massachusetts, found the absorbent power for water of the Ransome stone, when treated first in vacuo, and then under atmospheric pressure under water, to be $15\frac{79}{100}$ per cent. as the mean of three trials. Another sample made under different circumstances, but treated similarly, absorbed 17 per cent. of water. He says the stone "is as firm as any sandstone used in this country, and possesses no more absorbent power."

138. **Strength**.—Ransome's stone possesses, with a liberal factor of safety, ample strength to resist all the strains to which it would ordinarily be subjected as a building material.

139. D. D. Ansted, Esq., F. R. S., Professor of Geology at King's College, London, submitted a paper at a meeting of the British Association, at Cambridge, in 1862, which furnishes the following extract :

"The Transverse Strength.—A parallel bar of Ransome's concrete stone, measuring 4 in. by 4 in., and resting upon iron frames so as to bear one inch on the iron at each end, with 16 inches clear between the supports, sustained a weight suspended from the centre of 2,122 lbs. ; a bar of natural Portland stone of the same dimensions, treated similarly, broke at 759½ lbs."

Tensile Strength or Adhesive Power.—The tensile strength was determined by tests applied to pieces of stone, having a sectional area of 5½ square inches at the weakest point, and suitably notched near the ends so as to be embraced by clamps.

The following results were obtained :

Specimens of Stone Tested.	Area of Cross Section.	Total Tensile Strength of Block.	Tensile Strength per square inch.
1. Ransome's Patent Stone....	5½ square inches	1,980 lbs.	360 lbs.
2. Natural Portland Limestone	5½ " "	1,104 "	201 "
3. " Bath Stone........	5½ " "	796 "	145 "
4. " Caen Stone........	5½ " "	768 "	140 "

A 4-inch cube of Ransome's stone was found to sustain a weight of 30 tons before it was crushed, equal to a strength to resist crushing of 4,200 lbs. to the square inch.

Both the transverse and the tensile strength of the Ransome stone, given above by Professor Ansted, are much greater than the results obtained by Mr. G. M. Williams, of Hale Cliff, England, from the same kind of stone manufactured by himself, and reported in a paper read at the meeting of the Liverpool Architectural Society, December 27, 1865, as follows :

STRENGTH OF RANSOME'S PATENT CONCRETE STONE,

MANUFACTURED BY G. M. WILLIAMS, OF HALE CLIFF, ENGLAND.

140. "Comparative trials of the strength of the above stone, and of some of the natural stones in use for building in the Liverpool district, were made October 1, 1864, at Hale Cliff, England, in presence of several of the architects of Liverpool and other gentlemen.

"The blocks of stone used for testing the transverse strength were 4 inches square (in cross section) and 18 inches long, and were supported upon bars an inch from each end, giving a bearing of 16 inches, and the weight was applied to the centre.

"The pieces used for testing the adhesive power (or tensile strength) were bars having a sectional area of 5½ square inches, with projections at the ends to allow of their being torn asunder.

"The comparison between the natural and artificial stones, as to their power of absorbing water, showed that there was little difference, the artificial stone, made with coarse sand, taking up about the same quantity of water as the coarse-grained natural stone, and that made of the fine sand taking up about the same as the fine-grained natural stones. The water absorbed ranged from 12½ per cent. taken up by the coarse-grained stones, to

$6\frac{1}{4}$ per cent. taken up by those of fine grain. The stones were all thoroughly dried before being placed in water."

TRIALS OF TRANSVERSE STRENGTH, SHOWING THE BREAKING WEIGHTS.

Red Sandstone, 16 ins. clear, 4″×4″.	Stourton, 16 ins. clear, 4″×4″.	Minera, 16 ins clear, 4″×4″.	Freestone, kind unknown, 16 ins. clear, 4″×4″.	Patent Concrete, 16 ins. clear, 4″×4″.
10 cwt.	7 cwt.	Coarse, 7 cwt.	$12\frac{1}{2}$ cwt.	12 cwt.
This stone was from Woolton quarry, and has been exposed to the air for many years	$6\frac{1}{2}$ "	Fine, 8 "	$12\frac{1}{2}$ "	$11\frac{1}{2}$ "
	....	....	....	15 "
	....	....	....	12 "
Average......	$6\frac{3}{4}$	$7\frac{1}{2}$	$12\frac{1}{2}$	$12\frac{5}{8}$

Two other blocks of a fine-grained heavy stone of the same dimensions, supposed to be from Yorkshire, broke at $17\frac{1}{2}$ and $21\frac{1}{4}$ cwt.

On the 26th of November, 1864, a further number of blocks of concrete stone of the same size were tested, when the breaking weights ranged between 11 and $14\frac{1}{4}$ cwt. Two similar blocks, made of sand, now (December, 1865) used at the Hale Cliff Works, were lately tested, and the breaking weight was $16\frac{3}{4}$ and $17\frac{1}{4}$ cwt.

Four blocks of concrete stone, of the same size, of the quality prepared for filters, very open and porous, were tested, and the breaking weights were $9\frac{3}{4}$, $9\frac{3}{4}$, 9, and 11 cwt.

TRIALS OF ADHESIVE POWER OR TENSILE STRENGTH, SHOWING THE BREAKING WEIGHTS.

Sectional Area, $5\frac{1}{2}$ Square Inches.

Stourton, Under $3\frac{1}{2}$ weight.	Minera, Under $3\frac{1}{2}$ cwt.	Freestone, kind unkn'n,	Ransome's Stone.	
			Total Strength.	Tensile strength pr. sq. in.
This was the smallest weight which the arrangement of the machine admitted of applying, and on trial it was obvious that this was considerably more than either stone would bear.		$5\frac{1}{4}$	$4\frac{3}{4}$ cwt.	87 lbs.
		$7\frac{1}{2}$	9 "	183 "
		....	5 "	102 "
		. .	$5\frac{3}{4}$ "	117 "
		....	$5\frac{3}{4}$ "	117 "
		....	$7\frac{1}{2}$ "	153 "
Average		$6\frac{3}{8}$	Over $6\frac{1}{4}$ cwt.	

141. The age of the specimens of Ransome's stone above named is not given, from which it may be presumed that they were considered to have attained the maximum strength.

They possessed about the same crushing and tensile strength as béton Coignet of good quality, ten months old, or that of medium quality, suitable for plain walls, when twenty months old.

Good béton Coignet ultimately attains nearly twice the crushing strength of the Ransome stone tested by Professor Ansted.

142. An article in the London *Engineering*, for June 28, 1867, reports the trials of blocks of Ransome's stone and of Bath stone with the following results :

STRENGTH TO RESIST CRUSHING.

Kinds of Stone Tested.	Size of Blocks.	Total Crushing Weight.	Crushing Weight per square inch.
1. Ransome's Concrete Stone	4″ × 4″ × 4″	48 tons.	6,720 lbs.
2. Ransome's Concrete Stone.	4″ × 4″ × 4″	44 "	6,160 "
3. Bath Stone......	4″ × 4″ × 4″	14 "	1,960 "

TENSILE STRENGTH, OR ADHESIVE POWER.

	Area of Cross Section.	Total Tensile Strength of Block.	Tensile Strength per square inch.
1. Ransome's Concrete Stone.	2¼ square inches.	870 lbs.	386 lbs.
2. Ransome's Concrete Stone.	2¼ square inches.	1,200 "	533 "

143. By a comparison of the foregoing tables made up from all the experiments known to have been published up to the present time, and assuming them to be trustworthy, it will be seen that the tensile strength of Ransome's stone is extremely variable, ranging from 97 pounds to 533 pounds to the square inch. Its strength to resist crushing, obtained with 4-inch cubes, reaches as high for the best specimens as 6,720 pounds to the square inch, or about twelve times the tensile strength per inch of the same material.

144. The crushing strength of the weakest specimens reported —that giving a tensile strength of 97 pounds to the inch— would probably not exceed 1,200 to 1,500 pounds to the inch on 4-inch cubes.

The crushing strength of béton Coignet of best quality, two

years old, reaches as high as 7,500 pounds to the square inch, while for ordinary qualities, suitable for foundations and massive walls, a lower standard of strength, and consequently a reduction in the cost, is at the option of the builder, by increasing the proportion of sand.

146. The crushing strength of the béton Coignet, used in the church at Vesinet, near Paris, was only 2,634 lbs. to the square inch, which was regarded as ample for the purpose.

147. In making comparisons of strength it should be remembered that Ransome's stone does not materially improve in strength and hardness after it is a few weeks old, while béton Coignet, and indeed all mixtures of hydraulic cement or hydraulic lime and sand, continue to indurate for a period of two to two and a half years, and require fully three months to acquire one-third of their greatest attainable strength.

148. The Ransome stone, in consequence of the necessity for immersing the moulded blocks in a bath of hot chloride of calcium, is, of course, not adapted to monolithic construction, in which the béton Coignet finds its most advantageous application. The former, however, has this advantage, that the stone will bear transportation as soon as made, while the Coignet piece work must remain undisturbed for at least two days, even for small blocks, and a longer period for larger ones.

149. The labor expended in the making, costs much more than that required for béton Coignet, even in blocks. The measuring, mixing, and moulding into form, of the materials, and the removal of the block from the mould, are operations necessarily common to the two processes; but that of Coignet is completed here, while by Ransome's the moulded work must next be drenched with the cold chloride, then placed in a hot chloride bath, and subsequently removed therefrom and drenched with water before the stone is finished.

150. The Ransome stone is adapted to many descriptions of architectural embellishment, such as cornices, capitals, door and window dressings, copings, balusters, finials, &c.; for garden decorations, such as fountains, vases, statues, gate piers, balustrades, borders, &c.; for steps, pavements, grindstones, slabs, tiles, &c.; for monuments, tombs, gravestones, and other cemetery requirements.

151. The "Patent Concrete Stone Company," operating the Ransome process, have extensive works at East Greenwich, near London, where work of almost any pattern can be procured.

The manufacture of grindstones has become a very important branch of the business; 19 different sizes are made, ranging from 1 foot to 6 feet in diameter, and from 2 inches to 12 inches in thickness. The retail prices vary from 70 cents gold, for a stone 12 inches diameter and 2 inches thick, to $\$76\frac{00}{100}$ gold, for a stone 6 feet in diameter and 1 foot thick, equal to about $\$2\frac{70}{100}$ per cubic foot, with an extra charge in all cases for packing. The medium sizes sell for about $2.00 per cubic foot. These grindstones, being perfectly uniform in hardness, and homogeneous in structure, have been found to be greatly superior to those made from the best natural sandstones of England. They possess the additional advantage, that by a judicious selection of the sand of which they are made, their grain and texture can be specially adapted to any particular class of work.

152. Competitive trials of Mr. Ransome's artificial grindstones and natural Newcastle stones were made in England by Messrs. Ryan, Donkin & Co., early in 1867, with the following results:

A bar of steel $\frac{3}{4}$ in. in diameter, was placed in an iron tube containing a spiral spring, and the combination was then arranged so that the end of the bar projecting from the one end of the tube barely touched one of the artificial stones, whilst the other end of the tube rested against a block of wood fixed to the grindstone frame. A piece of wood of known thickness was then introduced between the end of the tube and the fixed block, and the spiral spring being thus compressed, forced the piece of steel against the grindstone. The same bar of steel was afterwards applied in the same way, and under precisely the same pressure, to the Newcastle stone, and the times occupied in both cases in grinding away a certain weight of steel from the bar were accurately noted.

The results were that a quarter of an ounce of steel was ground from the bar by the artificial grindstone in *sixteen minutes*, whilst to remove the same quantity by the Newcastle stone occupied *eleven hours;* and this, notwithstanding that the surface speed of the latter was more than 20 per cent greater. Taking the 20 per cent. greater speed of the Newcastle stone into account, it will be seen that the 11 hours run by it were equal to $13\frac{3}{4}$ hours at the same speed as the artificial stone, and the proportional times occupied by the two stones were thus as 16 minutes to $13\frac{3}{4}$ hours, or as 1 to 52 nearly!

153. The retail prices of Ransome's stone at the works, in

blocks containing from $1\frac{1}{2}$ to 3 cubic feet, according to the published price list are—

For plain building blocks, \$1.50 gold, per cubic foot.
For plain rustic coins with chamfered corners, \$1.55 per cubic foot.
For " " with ornamented face, \$1.70 to \$1.85 "

154. M. Coignet's price list shows that similar work is delivered at his manufactory at St. Denis, for from 65 to 70 cents per cubic foot. Either Company would doubtless undertake large contracts at a reduction of perhaps 30 per cent. on these prices, while massive monolithic constructions, to which the Ransome stone is not applicable, can be executed in France in béton Coignet with a fair profit at from 25 to 30 cents per cubic foot. Stones for architectual and other kinds of embellishment, of course cost more than the prices above quoted, both at St. Denis and at Greenwich, depending on the degree of ornamentation required, and the kind of mould necessary to produce it, the most expensive work being that which requires plaster moulds in many pieces.

155. **Ransome's process for hardening and preserving stone, brick, etc.**—Mr. Ransome has applied to the hardening and water-proofing of soft and porous stone, bricks, stucco, &c., the same principle upon which his manufacture of artificial stone rests for its novelty and value, and he employs the same chemical compounds in the one case as in the other.

156. Inasmuch as no engineer or architect would, knowingly, construct in stone or bricks of such inferior quality as to require the use of artificial means of preservation from decay, this hardening process finds its application limited to walls and buildings already constructed.

157. The process is described in general terms in paragraph 600, Gillmore's Treatise on Limes, Hydraulic Cements and Mortars, and consists in first washing the stone thoroughly with a solution of silicate of soda, and afterwards with a solution of either the chloride of calcium or the chloride of barium. The calcium solution is in most general use. In order to insure success the following rules should be observed :

1. The surface of the stone, &c., should first be thoroughly cleaned by the removal of any extraneous matter, and should also be perfectly dry before being operated on.

2. The prepared silicate of soda should be diluted with water (soft or rain water where convenient), in such proportions as may be necessary to admit of its being absorbed freely into the

structure of the stone or bricks, &c. If the material be of a very absorbent character, about an equal quantity of water will be found sufficient; but if of a close or dense texture about two parts of water, or in some cases even three parts of water should be mixed with one of silicate.

The prepared silicate, diluted as above, should be applied freely, but evenly, by means of a brush, to the surface of the stone, &c., and when properly absorbed, the operation should be repeated until the stone, &c., is thoroughly charged; but care must be taken not to allow any excess of silicate to remain upon the face when dry.

3. After a day or two when the silicate has *become perfectly dry* the prepared chloride of calcium should be applied freely (but brushed on lightly), so as to be absorbed with the silicate *in the structure of the stone*, when a double decomposition will immediately take place, and an insoluble *silicate of lime* will be precipitated, filling up the pores of the stone or other material, and firmly aggregating and cementing together the various particles of which the same may be composed.

4. In some cases it may be desirable to repeat the cperation, and as the precipitate thus formed by these two solutions is white or colorless, in the second dressing the prepared calcium should be tinted to produce a precipitate to harmonize with the natural color of the stone.

158. The wholesale price of silicate of soda, in London, is about \$1.37½ per gallon, gold, and of chloride of calcium \$1.12½ per gallon. The tinting solutions cost from 85 to 90 cents per pint.

159. This preserving process has been applied to quite a number of buildings, as well as to monuments, tombstones, &c., in England and the East Indies, and although its success has not in all cases been so decided as to command uniform approval, it is very generally admitted, by those familiar with its use and history, to be a valuable invention. No soft and porous stone can be properly treated by it without positive benefit. It hardens and strengthens the stone, renders it more nearly impervious to water, and does not occasion unsightly effervescence upon the surface if properly applied.

160. Its power of rendering brick walls practically waterproof, gives it great value in localities destitute of low-priced building stone.

THE FREAR ARTIFICIAL STONE.

161. In 1868 Letters Patent were issued in the United States to Mr. George A. Frear for "Improvement in composition for artificial stone, stucco, &c."

162. The only peculiar feature claimed for Mr. Frear's process is the use of gum shellac for increasing the strength and hardness of the artificial stone, stucco, etc., to which it is added.

In its application to artificial stone the shellac is added to a mixture of hydraulic cement and sand in the following manner:

163. The cement is incorporated with the sand while dry in such proportions as shall completely fill the voids—say one measure of cement, not compacted, with two and a half measures of sand—and the mixture is then moistened with a solution obtained by dissolving one pound of gum shellac in two to four ounces of concentrated alkali in aqueous solution.

This is diluted with water to that degree that about one ounce of the shellac is distributed through the cement and sand used in making one cubic foot of the stone. The dampened mixture, after thorough incorporation, is placed in strong moulds of the required form, and subjected to heavy pressure by machinery. The amount of pressure varies from fifteen to twenty-five tons per block, depending on the size of the latter.

On being taken from the mould, which may be done at once, the block of stone is allowed to dry two or three days, and is then dampened and exposed to the atmosphere, where the hardening process goes on. Ordinary blocks, such as sills, steps, &c., may be used in two or three weeks.

164. The pressing machines designed by Mr. Frear are of three sizes, as follows:

No. 1 will press a stone 12″ × 28″ × 6″ in size, equal to 31½ bricks. It will also press six bricks at a time, each 4″ × 6″ × 12″, designed to lay a solid wall one foot thick, or by laying them six inches to the weather, a double or hollow wall, one foot thick, can be made, leaving the inside face in suitable condition to receive the hard finish, without the first and coarse coat of plaster.

This machine, with four hands, will, it is claimed, press an amount of stone equal in quantity to from 10,000 to 12,000 common bricks per day. The price of this machine, delivered for shipment, is $300.

No. 2 will press a stone measuring 6″ × 10″ × 22″, and No. 3 one 6″ × 4″ × 28.″

165. The Company engaged in manufacturing stone under the Frear patent publish the following report from the Inspector of Ordnance in the Washington Navy Yard, as testimony regarding the strength and value of their stone :

"Ordnance Office, Navy Yard,
Washington, D. C., *March 10th*, 1869.

"The following are the results of a test of building material presented by Mr. Charles Holland, of Chicago, through Mr. David A. Burr, and called by him Frear stone:

	Height.		Base.		Depth.
Cube	1.27 in.	×	1.30 in.	×	1.29 in.

Compression.	Strength.
1 in 270	300 lbs.
1 " 270	1,000 "
1 " 270	2,000 "
1 " 265	3,000 "
1 " 265	4,000 "
1 " 265	5,000 "
1 " 265	6,000 "
Crushed	6,050 "

"The specimen is not an exact cube, as is seen above. The measurements indicate the position of the stone in the machine when crushed.

"(Signed) W. R. Reese,
"*Commander U. S. Navy,*
"*Inspector of Ordnance.*"

The results recorded in Commander Reese's report give a crushing strength of 3,607 lbs. to the square inch. This is less than one-half the strength of the best béton Coignet, tried at Paris, in July, 1864, by Mr. P. Michelot, Chief Engineer in the Ponts et Chaussées, which gave a crushing strength of 7,495 pounds to the square inch, while fourteen different qualities of béton tested by the same officer, at the same time, gave an average crushing strength of 4,670 pounds to the square inch.

166. Several two inch cubes tested by the writer in the presence of Mr. Frear, in April, 1871, gave the results recorded below.

The composition of the blocks, as reported by Mr. Frear, was one measure of hydraulic cement, two and a-half measures of sand, moistened with an alkaline solution of gum shellac, of

sufficient strength to furnish one ounce of the shellac to one cubic foot of the finished stone. Portland cement was used in Nos. 1, 2, and 3, and Louisville cement in No. 4. The ages of the stone are those reported by Mr. Frear.

No. 1.	2 inch cube, four weeks old, crushed at	18,000 lbs.,	or	4,500 lbs.	per	square	inch.
No. 2.	2 inch cube, " "	18,500	"	4,626	"	"	"
No. 3.	2 inch cube, three weeks old, crushed at	9,000	"	2,250	"	"	"
No. 4.	2 inch cube, six months old "	8,000	"	2,000	"	"	"

A four-inch cube, of the same composition and age as Nos. 1 and 2, sustained 57,000 lbs., equal to 3,562½ lbs. to the superficial inch under compression, and was not crushed.

167. Some of the Frear stone used in the construction of dwelling-houses, in Chicago and other Western localities, has not thoroughly withstood the effects of the climate. The failures are not represented as numerous, and are by no means fatal in either extent or character, and may have been due to the use of inferior native cement. The cement, however, to which preference has generally been given, is that manufactured at Louisville, Kentucky, which, although generally somewhat inferior to the Rosendale brands, stands above the average of native varieties.

No Portland cement has been employed in making Frear stone in the West. It is superior to all others for this purpose.

The introduction of gum shellac undoubtedly adds to the strength of any mixture of hydraulic cement and sand, while that mixture is yet new, or only a few months old ; but whether it will tend to augment the strength and hardness acquired by age, particularly when Portland cement supplies the matrix, is certainly questionable.

Portland cement and sand alone, when properly mixed together with a small quantity of water, in proportions that shall leave no voids, make a good artificial stone, without the addition of shellac. This is known as Portland stone, and is briefly described in paragraph 200. It is not protected by any patent. This stone, however, like the Frear, is comparatively expensive, in consequence of the large proportion of cement required to avoid porosity. The addition of common or hydraulic lime, under such conditions as shall, as far as our present knowledge extends, secure the best results, produces béton Coignet.

The durability of gum shellac, when exposed to the weather, is by no means certain. It readily yields to the solvent action

of alkalies, and should be employed with caution in localities exposed to such influences.

THE AMERICAN BUILDING BLOCK COMPANY'S ARTIFICIAL STONE.

(THE FOSTER AND VAN DERBURGH PATENT.)

168. *Foster's process* consists in mixing together slaked lime and moist silicious sand, and then subjecting the mixture to great pressure in moulds, the moulded blocks being left to harden in the open air. Very little water is used, and the quantity of lime should not exceed what is required to coat each and every grain of sand, and fill up the voids in the compacted mass.

The cementing material in this stone is principally silicate of lime, slowly developed upon the surface of each grain of sand in contact with the lime, aided to some extent by the induration of hydrate of lime, and the formation of the double hydrate and carbonate of lime upon the surface of the block, and to the depth penetrated by the air.

The formation of the silicate of lime is very greatly facilitated by the pressure to which the material is subjected, which diminishes the volume of voids, and the thickness of the lime coating, and renders the contact of the sand and lime more intimate. All the lime should be exhausted in coating the sand grains, to the end that it may all be converted into silicate. Any surplus remains more or less inert, and destitute of energy.

169. By *Van Derburgh's process*, which is an improvement upon Foster's, ground *quick* lime, instead of slaked lime, is mixed with the moist sand, thus utilizing the heat developed by slaking, before the mixture is moulded and pressed.

Steam is also introduced into the loose mass to hasten the slaking, and the formation of the silicate of lime.

170. Professor Horsford, late of Harvard College, Cambridge, Mass., in his report upon the patents under which the improved process claims protection, says :

"Van Derburgh, by his process, as at present carried out in "practical working, intimately mixes *finely ground unslaked lime* "with moist sand, in a close chamber, kept in constant agi- "tation. The affinity of the unslaked lime for water causes the "lime dust to adhere wherever it touches the surface of the "moist sand. Slaking instantly commences, and is aided by the

"introduction of steam into this confined space. Under these "circumstances, the heat involved in slaking the lime, as well as "the heat due to the steam admitted to the interior of the con-"tinuously stirred and kneaded mixture, is brought to bear on "the silica, at the surface of the sand grains, in contact with the "moist hydrate of lime. After continuing in this condition for "a suitable time, it is subjected to great pressure, imparted by "successive percussions in metallic moulds. The pressure re-"sults in a block, the surface of which rapidly becomes hard, "and the hardness gradually extends from the surface toward "the heart of the mass."

171. Professor Horsford analyzed samples of the Foster artificial building stone of various ages, the oldest of which has been for eleven years in a foundation wall. "This sample was nearly as hard as Connecticut sandstone," and was the only one in which all the lime was found "combined and rendered substantially insoluble." Others, only a few months old, were found equally hard at the surface, in consequence, doubtless, of the formation of the carbonate as well as the silicate of lime, but they were less firm in the interior. "A fresh fracture of a block several years old, shows a zone of peculiar shade, extending from the outer surface toward the heart of the stone," marking the progress of certain chemical changes which accompany the indurating process, and illustrating its slow improvement by age. There is also a slow increase in the weight of the stone.

172. The Van Derburgh stone hardens more rapidly than Foster's, for the simple reason that when silica and *quick-lime* are brought together in the presence of moisture, heat is evolved, which in this case is increased and maintained by the introduction of steam, and it is well known that the formation of the silicate of lime is facilitated by heat. Moreover, the powder of *quick-lime* slaking in contact with the moist sand, as in the Van Derburgh process, becomes more homogeneously and uniformly distributed as a coating to the sand grains than it could be in the Foster process by mechanical means alone, after having been rendered in a certain sense inert by previous slaking.

Hence the Van Derburgh artificial stone has generally been found to be superior in strength, hardness, and homogeneity to stone of the same age made after the Foster patent.

173. Both processes are, however, susceptible of very great improvement in so far as they prescribe that the mixed materials

shall be compacted in the moulds by pressure, instead of by the superior method of tamping or ramming, as practised in making béton Coignet, and by the Union Stone Company, operating under the Sorel patent; for although Van Derburgh introduced tamping into his practice, it is not understood that he claims the right under his patents to employ that method of compacting the mixed materials.

The tardy induration of the Van Derburgh and Foster stone, and indeed of all artificial stone into which common lime enters as the only, or the principal source of the matrix or cementing medium, places them under great disadvantage when in competition with a stone having an energetic hydraulic lime or cement as its basis.

174. The Van Derburgh building blocks were used in the construction of the Howard University and Hospital buildings at Washington, District of Columbia, in 1868–69.

The blocks were of a uniform size, being ten inches long, five inches wide, and four inches deep, and weighed about eleven pounds each. They had a vertical air-chamber through the centre six inches long and one inch wide.

175. A portion of the building fell down during the progress of construction, a circumstance which led to a careful examination of this artificial stone by experts appointed for that purpose.

From the report of their trials furnished me by General O. O. Howard, the information contained in the following table has been condensed. It gives the crushing strength of the Van Derburgh building blocks taken from the Howard University Building and elsewhere. The trials were made under the superintendence of Engineer Major W. R. King, U. S. Navy, at the Washington Navy Yard, D. C., in February, 1869.

Size of Blocks 10″ long by 5″ wide by 4″ deep. Vertical air chamber through the centre 6″ by 1″ wide. Area under compression, omitting air chamber, 44 square inches.

		Age of Blocks.	Crushing Strength of Blocks.	Crushing Strength per sq. in. of top surface.
1	From first story Howard University, tested on metal bed............	12 to 13 months.	19,500 lbs.	443 lbs.
2	" second " " " " " "............	not known.	20,000 "	456 "
3	" third " " " " plaster "	6 months.	13,000 "	295 "
4	.... " metal "	11 "	16,900 "	384 "
5	.... " " "...	10 "	24,800 "	564 "
6	.... " " "..	9 "	15,500 "	352 "
7	Red block................. ...... " " "............	8 "	15,900 "	361 "
8	.... " " "............	7 "	12,000 "	273 "
9	.... " " "............	6 "	9,000 "	205 "
10	.... " " "..........	5 "	8,700 "	198 "
11	Damp......................... " " "............	4 "	7,600 "	173 "
12	.... " " "	3 "	7,900 "	180 "
13	Angle off block.. .... " " "............	15 to 16 months.	18,760 "	426 "
14	.... " " "............	about 12 months.	15,600 "	355 "
15	.... " " "............	ten years.	64,000 "	1,455 "
16	Made of yellow and loamy sand ; Refuse block tested on metal bed .	not known.	8,200 "	186 "
	Average strength of the blocks 1, 2, and 3 from the University building.	....	17,500 "	398 "
	" " " whole series, 1 to 16......................	....	17,353 "	394 "

PRACTICAL RESULTS.

176. "*1st.* It was found that the blocks increased in strength "according to their age at the rate of about 1,000 pounds per month.

"*2d.* Three thousand pounds per block are called for by the "actual pressure at the bottom of the first story of University. "Capacity as tested, 19,500 pounds per block.

"*3d.* Capacity of blocks in third or top story of University, "13,000 pounds.

"*4th.* Average capacity of blocks in the three stories, 17,566 "pounds.

"*5th.* The blocks were tested between naked metallic plates, "except in one instance, in a plaster bed between the plates "(plaster $\frac{1}{4}$ of an inch). In this case 4,000 additional pounds "were obtained, viz., instead of 9,000 pounds as blocks of August, "1868, bore in metal bed, the block of same age in plaster bed "(which is their true condition in building) bore 13,000 pounds.

"*6th.* These experiments were without any side support to the "blocks. In buildings of 15 inch walls, two-thirds of the blocks are "supported on three sides, and one-third of them on all sides. "The Navy Yard experts, Mr. John Holroyd and Mr. Wm. H. "Bradley, who made the tests, were of opinion that the results "obtained would be doubled as to blocks in a solid wall."

177. An additional series of five blocks of the same size and the same material, subjected to test at the Washington Navy Yard about the same time as those above recorded, furnished the following results, the blocks being crushed between metal plates, with a bed of plaster $\frac{1}{8}$ to $\frac{1}{4}$ of an inch in thickness, interposed, in every case, above and below :

		Age of Blocks.	Crushing Strength of Block.	Crushing strength per square inch.
17	....	10 months.	16,000 lbs.	364 lbs.
18	..........Cracked at 13,000 lbs..............	9 "	26,500 "	602 "
19	..........Slightly cracked at 18,900 lbs......	4 "	41,900 "	975 "
20	From Hospital ruins, cracked at 10,000 lbs..........	Not known.	44,000 "	1,000 "
21	" " " 20,000 "	Not known.	27,100 "	616 "
	Average of the five blocks, Nos. 17 to 21..........		31,100 "	707 "

PRACTICAL RESULTS.

178. "First. It was found that the plaster beds gave an increase over previous tests, of 13,767¼ pounds per block.

"Second. The average of the five blocks was more than ten "times the amount required at the bottom of the University "walls (3,000 pounds), and nearly sixteen times the amount required at the bottom of the Hospital walls (2,000 pounds).

"Third. The average of the two Hospital blocks was 35,500 "pounds, or about eighteen times the actual pressure of the "building."

REMARKS.

179. *First.* Size of blocks 10″ long, 5″ wide, 4″ deep. Area under compression, omitting air-chamber, 44 square inches.

Second. The weakest block crushed at 7,600 pounds (4 months old). The strongest block crushed at 64,000 pounds (10 years old). Average crushing strength of all the blocks, 24,231 pounds. Average crushing strength of blocks known to be between one and two years old, 17,953 pounds.

Third. By dividing the total crushing strength of block by the area in square inches on the top surface, we get what it is customary to call the crushing strength per square inch, although the results thus obtained exceed the crushing strength of a one-inch cube of the material, and the larger the block is on the top the greater will this excess be, on account of the lateral support which the central portion of the block receives from the material surrounding it. Making the reduction in this manner, however, as was done for the other tables in the work, the following results are obtained :

Crushing strength per square inch of weakest block, 173 pounds.
Crushing strength per square inch of strongest block, 1,455 pounds.
Average crushing strength per square inch of the twenty-one blocks, 551 pounds.

THE UNION STONE COMPANY, BOSTON.

180. **The Sorel Process.**—It was stated in the Report on Béton Aggloméré, paragraph 15, that "as a rule all hydraulic cements produced at a low heat, whether derived from argillaceous or argillo-magnesian limestones, are light in weight and quick setting," and are inferior for mortar or béton, to Portland cement or good hydraulic lime. The argillaceous and argillo-magnesian limestones here referred to, belong to that class which furnish

cements in virtue of the compounds of lime formed in the kiln, as indicated in paragraph 17. These compounds are not formed until after carbonate of lime is reduced to quick-lime. The cement derived from magnesite, at a low heat, does not come within the class above named, as the stone is neither argillaceous nor argillo-magnesian.

181. The hydraulic properties, when properly burnt, of many of the varieties of dolomitic limestones, became theoretically known many years ago, but the utilization of this knowledge, so as to render it of practical value in the builder's art, is of quite recent date. Carbonate of magnesia parts with its carbonic acid, and is converted into oxide of magnesium, at a temperature of from 300° to 400° Centigrade, or below that which produces a dark cherry red. The production of lime, or oxide of calcium, requires a heat of greater intensity. It is practicable to burn a magnesium limestone so as to convert the carbonate of magnesia into oxide of magnesium, while the bulk of the lime remains a carbonate.

182. A paste made from dolomite, calcined below a cherry red heat and then reduced to powder by grinding, forms under water an artificial stone of considerable hardness. If the heat, however, be sufficiently intense to reduce the carbonate of lime also—say above 400° Centigrade—thus forming quick-lime, the addition of water causes slaking, and the hydraulic energy is destroyed or impaired by the presence of hydrate of lime.

183. Any magnesian limestone containing as high as 60 per cent. of carbonate of magnesia, may be presumed to be capable of yielding a good hydraulic cement if properly burnt. In the process of burning, however, great care is required. The temperature must be increased slowly to a dark cherry red heat, and maintained there until the carbonic acid is expelled from the magnesia. The lime remains in the form of carbonate. The burnt product must then be reduced to an impalpable powder, in order to fully develop its hydraulic energy.

Magnesia obtained by calcining the chloride below a red heat, also exhibits remarkable hydraulicity, while the product resulting from a white heat is nearly destitute of this property.

184. **M. Sorel's Discovery.**—M. Sorel, an eminent French chemist, discovered the oxychloride of magnesium to be a hydraulic cement of great strength and hardness. This cement is the basis of the artificial stone manufactured by the "Union Stone Company," and is produced or formed by adding a solu-

tion of chloride of magnesium, of the proper strength and in the proper proportions, to the oxide of magnesium obtained by calcining carbonate of magnesia, or *magnesite.*

185. The several steps in the process, beginning with the raw magnesite, are briefly as follows, viz. :—

First.—The magnesite is burnt in ordinary lime-kilns, at a dark cherry red heat, for about 24 hours. The result is protoxide of magnesium, which is next ground to fine powder between horizontal mill-stones, furnishing what the Union Stone Company style, "Union Cement."

Magnesite has been procured from various localities. That from Greece, California, Maryland, and Pennsylvania, contains about 95 per cent. of carbonate of magnesia, the residue being mostly insoluble silicious matter. The burnt product is perfectly white.

A magnesite is procured in Canada, which contains from 60 to 85 per cent. of carbonate of magnesia. A variable percentage of iron in the residue, gives the cement derived from this stone a reddish tint. The reports of State Geological Surveys indicate that magnesite exists in numerous localities in the United States.

Second.—For making stone, the burnt and ground magnesite (oxide of magnesium) is mixed dry in the proper proportion with the material to be united, that is, with powdered marble, quartz, emery, silicious sand, soapstone, or with whatever substance forms the basis of the stone to be imitated or reproduced.

The usual proportions are for emery-wheels 10 to 15 per cent. of oxide of magnesium, by weight, for building blocks such as sills, lintels, steps, &c., 6 to 10 per cent., and for common work for thick walls, less than 5 per cent.

The dry ingredients are mixed together by hand or in a mill. A hollow cylinder revolving slowly about its axis would answer the purpose.

Third.—After this mixing they are moistened with chloride of magnesium, for which bittern water—the usual refuse of seaside salt works—is a cheap and suitable substitute. The moistened material is then passed through a mill, which subjects it to a kind of trituration, by which each grain of sand, or other solid material, becomes entirely coated over with a thin film of the cement, formed by a combination of the chloride with the oxide of magnesium. The bittern water is required to be of the density of from 15° to 30° Baumé. The mass on emerging from the

mill should be about as moist as moulder's clay. The mixing machine used by the "Union Stone Company," is an improved pug mill invented by Mr. Josiah S. Elliott. It is represented as an excellent mill, doing its work thoroughly.

Fourth.—The mixture is formed into blocks by ramming or tamping it in strong moulds of the required form, made of iron, wood, or plaster, precisely as described in paragraph 24, Report on Bèton Aggloméré.

186. The block may be taken out of the mould at once, and nothing further need be done to it. The setting is progressive and simultaneous throughout the mass, as with other hydraulic cements, and requires from one hour to one day, depending somewhat on the chemical properties of the solid ingredients used, the carbonates as a rule requiring a longer time than the silicates.

Building blocks will bear handling, and may be used when three or four days old, although they do not attain their maximum strength and hardness for several months.

Emery wheels are not allowed to be used in less than four weeks.

187. This stone so closely resembles the natural stone, whether marble, soapstone, sandstone, &c., from which the solid ingredients are obtained by crushing and grinding, that it is difficult, without the application of chemical tests, to detect any difference in either texture, color, or general lithological appearance.

STRENGTH.

188. In strength and hardness, this stone greatly surpasses all other known artificial stones, and is equalled by few, if any, of the natural stones that are adapted to building purposes.

The artificial marble takes a high degree of polish, being in this respect fully equal to the best Italian varieties.

189. Some trials of 2-inch cubes at the Boston Navy Yard gave the following results, reduced to the crushing pressure upon one square inch :

No. 1,	crushing strength	per square	inch,	7187½ lbs.
No. 2,	"	"	"	11562½ "
No. 3,	"	"	"	21562½ "
No. 4,	"	"	"	7343½ "

In none of these samples did the proportion of the oxide of magnesium exceed 15 per cent. by weight of the inert material

cemented together. This statement is derived from the Treasurer of the Company.

The principal business of the Union Stone Company up to the present time, has been the manufacture of emery wheels. The great tensile strength of the material may be inferred from the fact, that in the proof trials, the wheels are made to revolve with a velocity of from 2 to 3 miles per minute at the circumference. They do not usually begin to break until a velocity of from 4 to 5 miles per minute is attained.

191. From a number of specimens of this stone furnished the writer by the Treasurer of the Company, who also gave their age and composition as reported below, comprising coarse and fine sandstone of various shades of color, hones, white and variegated marble, emery wheels, billiard balls, concrete building blocks, &c., some small blocks were prepared and subjected to crushing with the following results.

	Character of the Inert Materials.	Proportion by weight of Oxide of Magnesium.	Age of Blocks.	Size of Blocks.	Total Crushing Strength.	Crushing Strength per square inch.
1	Coral Sand........	12 per cent.	1 year.	$2'' \times 2\frac{1}{8}'' \times 1\frac{7}{8}''$	26,500 lbs.	6,235 lbs.
2	Pulverized Quartz.....	12 to 15 "	1 "	$1\frac{3}{8}'' \times 2'' \times 1\frac{3}{8}''$	20,000 "	7,272 "
3	Washed flour of emery (a piece of hone)	Not known.	2 "	$1\frac{3}{8}'' \times 2'' \times 1\frac{3}{8}''$	54,000 "	19,636 "
4	Fine Marble........................	15 per cent.	3 "	$1\frac{1}{2}'' \times 1\frac{1}{2}'' \times 1\frac{1}{2}''$	26,000 "	11,555 "
5	Mill sweepings	12 to 13 "	9 months.	$1\frac{7}{8}'' \times 2'' \times 1\frac{7}{8}''$	23,000 "	6,133 "
6	Marble and Sand....................	12 "	2 years.	$1\frac{5}{8}'' \times 2'' \times 1\frac{1}{2}''$	16,000 "	4,923 "
7	Marble with Colored Veneer.........	Not known.	Not known.	$1\frac{1}{4}'' \times 1\frac{1}{4}'' \times 1''$	12,000 "	7,680 "

DURABILITY.

192. The proofs of the durability of the Union stone rests upon other evidence than that furnished by severe and prolonged climatic exposure. In Boston, however, building blocks have resisted two winters, and at the present time appear to be, and doubtless are harder and stronger than before they were touched with frost.

Dr. C. T. Jackson, State Assayer of Massachusetts, reports upon it as follows :

"I find that the frost test (saturated solution of sulphate of "soda) has not the power of disintegrating it in the least. The "trial was made by daily immersions of the stone in the sulphate "of soda solution for a week, and allowing the solution to pene-"trate the stone as much as possible and then to crystallize. "From this test it is evident that your stone will withstand the "action of frost more perfectly than any sandstone or ordinary "building stone now in use. I see no reason why it will not "stand as well as granite."

193. A *perfect* resistance to the freezing and thawing of one winter may safely be accepted as conclusive evidence of the durability in the open air, of an artificial stone of which the matrix is any kind of hydraulic cement. At no subsequent period will it be as likely to fail, from freezing and thawing, as during the first winter.

194. A stone suitable for all kinds of building purposes on land might, however, fail under the solvent action of sea water. On this head it can be said that magnesian compounds are understood to resist the immersion in the sea better than the compounds of alumina or lime.

COST.

195. Assuming that the magnesite, in the undeveloped ledge, costs no more than a bed of hydraulic cement stone, and that the facilities for working the quarry are equal in the two cases, the oxide of magnesium could be manufactured as cheaply as hydraulic cement. There will be a tendency to this equality in price, as new beds of magnesite are discovered and made available, and the demand for this new cement increases.

The process of manufacture is the same in both cases, that is, the stone has to be quarried, burnt, and ground; with this advantage in favor of the magnesite, that a less intense heat, and con-

sequently less fuel, is needed for its proper calcination than hydraulic cement requires.

196. The "Union Stone Company" have fixed the selling price of their ground oxide of magnesium at five cents per pound, which is eight times the wholesale market price of Rosendale cement in New York, and five times the price at which the best Portland cement may be imported by the cargo, inclusive of custom-house duties. The chloride of magnesium is another source of expense in the Sorel process; for although bittern water is a cheap substitute, and in the vicinity of sea-side salt works may be procured for little or nothing, its cost amounts to no inconsiderable item when it has to be transported to a distance.

For these reasons, this new stone has, with some exceptions, been limited in its application to articles of small bulk and great comparative value, for which other approved and less expensive artificial stone is either not suitable, or of less practical value. Although for architectural ornaments of elaborate design it is perhaps less costly, even now, than granite or marble, it cannot hope to compete successfully for general adoption and use by engineers and architects, with the béton aggloméré, and the softer kinds of natural stone, until the market price of the oxide of magnesium is greatly reduced. For the peculiar purposes to which it is adapted, it supplies what has heretofore been felt as a great want, and in this field, which is neither narrow nor unvaried, it has no prominent rival.

This subject is discussed with discriminating judgment in a report from which I make the following extract :

(*Extract from the Report of the Committee of the Middlesex Agricultural Society*, Hon. Simon Brown, Chairman.)

"Union Stone Companys' Articles.—Building stones and "bricks ; soapstone sinks and tubs without joints ; tiles, curb-"stones, posts, emery wheels, grindstones, mantel pieces, &c., "&c. This stone work is a new enterprise, and in the opinion "of the Committee promises to become one of great general "utility. The Committee learn that this Company has several "modes of manufacture, and have worked out and recorded more "than two thousand formulas, using in all cases the same cem-"entatious agent, *magnesia,* for which they have several Letters "Patent. The large stone upon which their goods were ex-"hibited, and upon which the spectators stood while examin-

"ing them, was made upon the spot, of *magnesian cement*, pre-"pared at the manufactory, and brought to the ground, where it "was mixed and moistened with the earth and gravel found "there! The whole mixture was then pounded down, and in "the course of a week was transformed into stone as hard as "granite!! The manufactured article partakes of the nature "and color of the mineral substance used. That is, broken soap-"stone is used to make soapstone, marble to make marble. The "amount of cement (magnesia) used is so small a proportion of "the whole mass as to make no perceptible change in color or "quality.

"The Committee were greatly interested in the articles pre-"sented by this Company—such as beautiful soapstone stoves, "whetstones, hones, medallions, with a surface as smooth as "polished ivory, emery wheels, and numerous other articles of "value. It does not seem improbale to the Committee that this 'device may be carried so far as to furnish coverings for build-"ings, tile, walls, outside chimneys, and even underpinning, "where stones cannot be had short of heavy cost of transporta-"tion."

197. The following formula has been found suitable for window-caps, sills, steps, &c. The quantities specified will make one cubic foot of stone.

100 pounds of beach sand, cost $1.00 per ton at the works...........	.05
10 " " comminuted marble, cost $5.00 per ton at the works....	.02½
10 " " Union cement (oxide of magnesium)..................	.50
10 " " chloride of magnesium in solution, 20° Baumé.	.02
130 pounds, yielding 1 cubic foot of moulded stone................	.59½

198. The labor, depending somewhat on the design as regards the degree and character of its ornamentation, will vary per cubic foot, from 20 cents to 25 cents, making total cost of one cubic foot of finished building block 79½ to 84½ cents. This price may be reduced 10 to 15 cents per cubic foot by incorporating large pebbles and small cobble stones during the process of moulding.

For foundations and other plain, massive walls, the proportion of cement may be very considerably reduced, and the quantity of cobble stones increased.

199. The principal source of profit to the "Union Stone Company" is doubtless the cement, of which they are presumed to have the monopoly.

If magnesite shall be found to be so plenty, and so generally distributed over the country, that the market price of the cement (oxide of magnesium) shall not greatly exceed that of Portland cement, which is now about $1.00 per 100 pounds in New York, this new artificial stone will not be more expensive than the common concrete made with American cement, while its remarkable strength, and the ease and certainty with which any desired shade of color can be attained, adapts the former to very many uses for which the latter is not suitable.

PORTLAND STONE.

200. What is known under the name of Portland stone, is simply a mixture of Portland cement and sand, or both sand and gravel. It possesses, when properly made, the essentials of strength aud hardness, in an equal degree with béton Coignet, but is considerably more expensive, unless the cost is kept down by reducing the quantity of cement to that extent which renders the mixture weak and porous.

Any of the methods of manipulation, by hand or machinery, described in the foregoing pages for béton Coignet, or for the Frear stone, will of course answer for Portland stone; that is, the cement, sand, and gravel are first thoroughly mixed up together, with a sufficient quantity of water to make a damp incoherent mass, and then rammed into the moulds for building blocks, or formed as monoliths.

There are no patents protecting the use of Portland cement in this way. On the contrary, it seems questionable whether the manufacture of Portland stone by the method that shall produce the best results, that is, by using the smallest quantity of water that will suffice, is not more or less an infringement of some of the Coignet patents.

GENERAL COMPARISON OF STRENGTH AND COST.

201. **Strength.** — Arranged according to their crushing strength, the several kinds of artificial stone described in the foregoing pages, assume the following order, from the strongest to the weakest :

1. The Sorel stone (Union Stone Company, Boston, Mass).
2. Béton Aggloméré or Coignet-Béton.
3. The Ransome Silicious Concrete stone.

4. The Frear stone.
5. The Portland stone.
6. The Foster and Van Derburgh stone (American Building Block).

The Sorel stone, in which the cement used is oxide of magnesium, stands prominently in advance of all the other kinds of artificial stone, in strength and hardness.

There is no marked difference between béton Coignet and Ransome's stone in crushing strength, nor again between the Frear and the Portland stone, assuming that the alkaline solution of gum shellac used in making the Frear is stable and enduring, and does not in process of time deteriorate, under the effect of alkalies and ammonias introduced from without.

202. **Cost.**—If the several stones be arranged according to their estimated cost, for the same character and class of work, they will assume the following order, from the lowest to the highest:

1. The Foster and Van Derburgh stone.
2. Béton Aggloméré.
3. The Portland stone.
4. The Frear stone.
5. The Ransome stone.
6. The Sorel stone.

There is but little difference in cost between the Frear and the Portland stone, and that is due to the use of shellac in the former. Omit this, and pursue the same method of mixing for both, and the two become identical in composition, strength, and cost.

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The numbers refer to the paragraph.

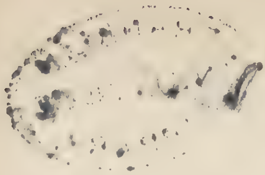
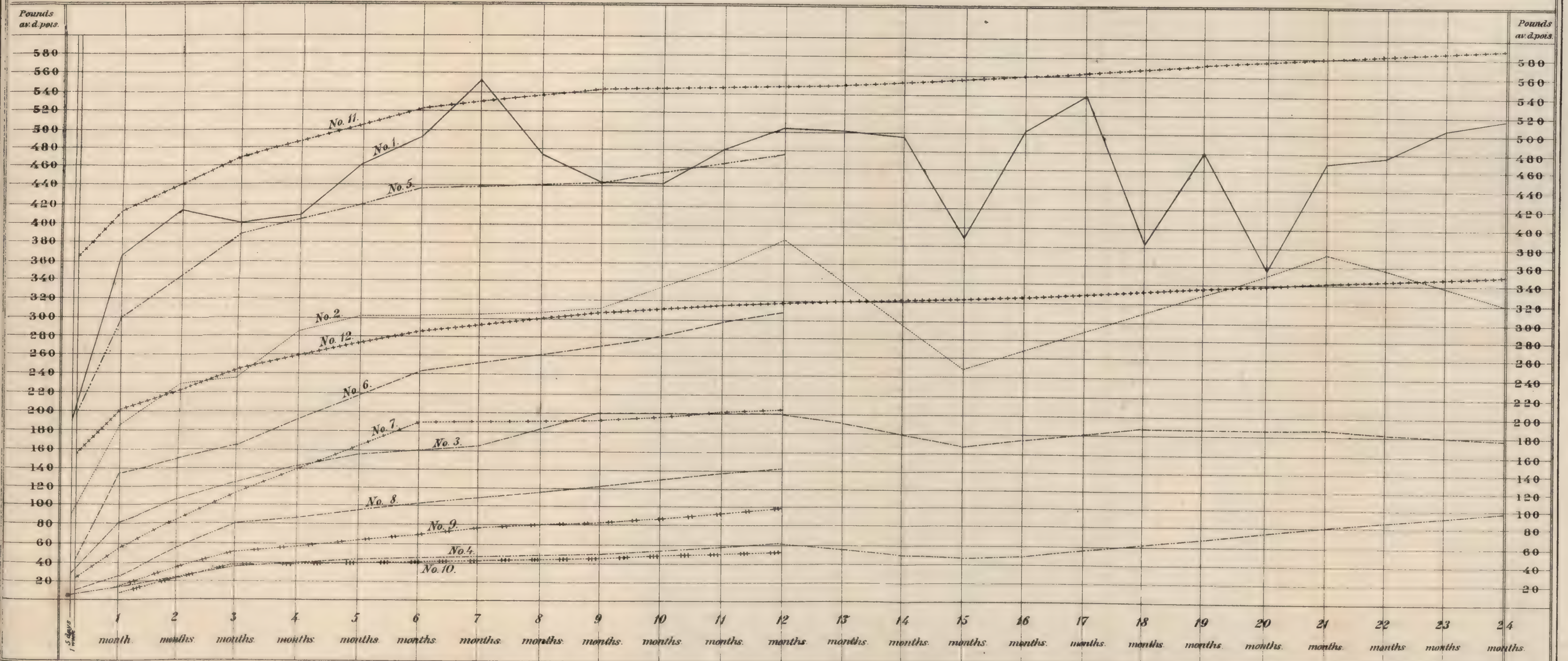


DIAGRAM SHOWING THE TENSILE STRENGTH PER SQUARE INCH OF PORTLAND CEMENT, WITH AND WITHOUT SAND, AT VARIOUS AGES.

LEGEND.

No. 1 ——— Boulogne Portland Cement 101 Lbs. per bushel, without sand.
" 2 .... " " " " " " " , 1 vol. cement 2 vol. gravel.
" 3 ——— " " " " " " " , 1 " " 4 " "
" 4 ——— " " " " " " " , 1 " " 10 " "
" 5 ——— English " " 109 " " " without sand.
" 6 ——— " " " " " " " , 1 vol. cement 1 vol. Thames sand.

No. 7 -+-+-+- English Portland Cement 109 Lbs. per bushel, 1 vol. cement, 2 vol. Thames sand.
" 8 ——— " " " " " " " , 1 " " 3 " " "
" 9 ++-++-++ " " " " " " " , 1 " " 4 " " "
" 10 -+++-+++ " " " " " " " , 1 " " 5 " " "
" 11 -+-+-+-+ " " " 120 " " " without sand.
" 12 ++++++++ " " " " " " " , 1 vol. cement 1 vol. sand.



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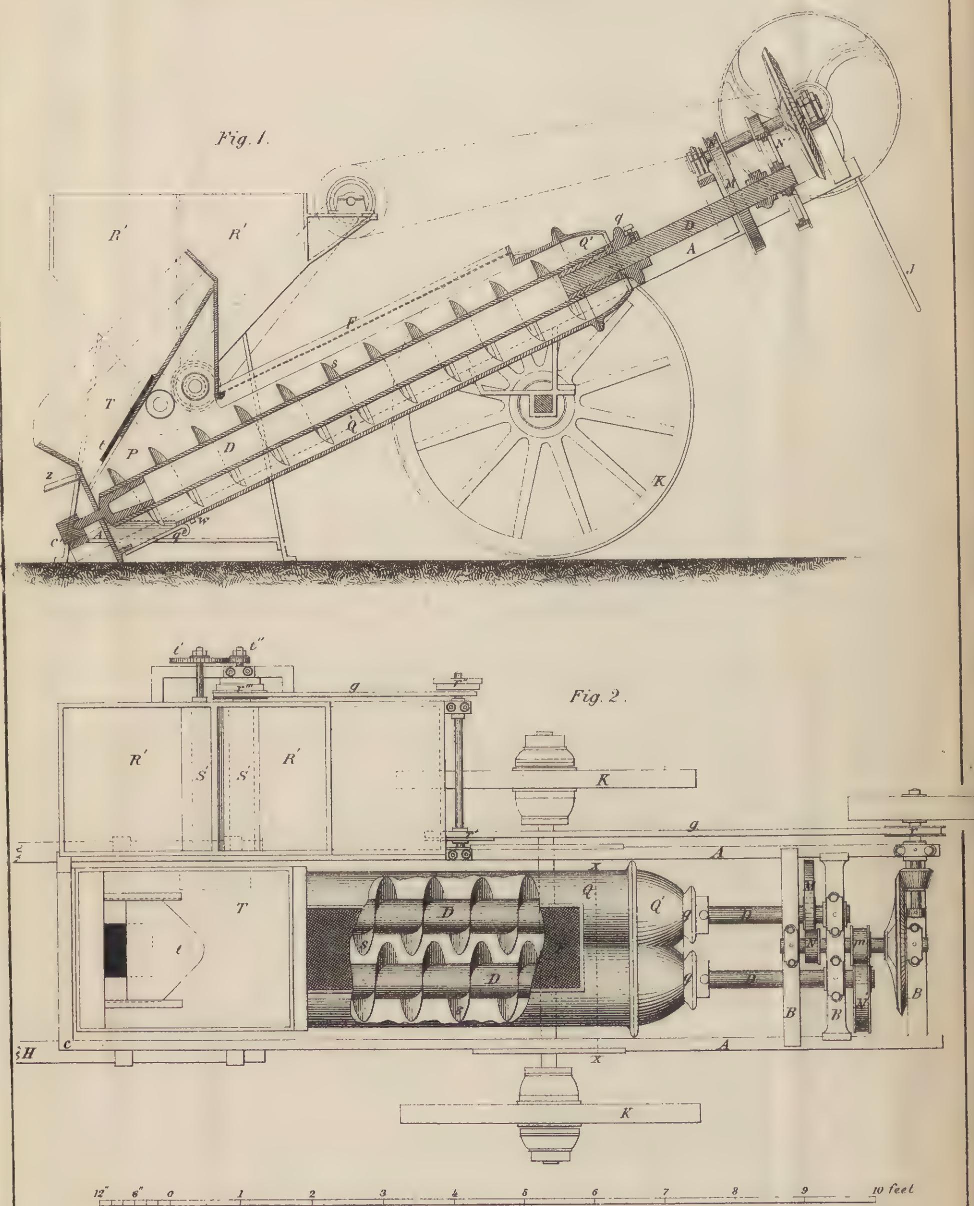
THE COIGNET MALAXATOR



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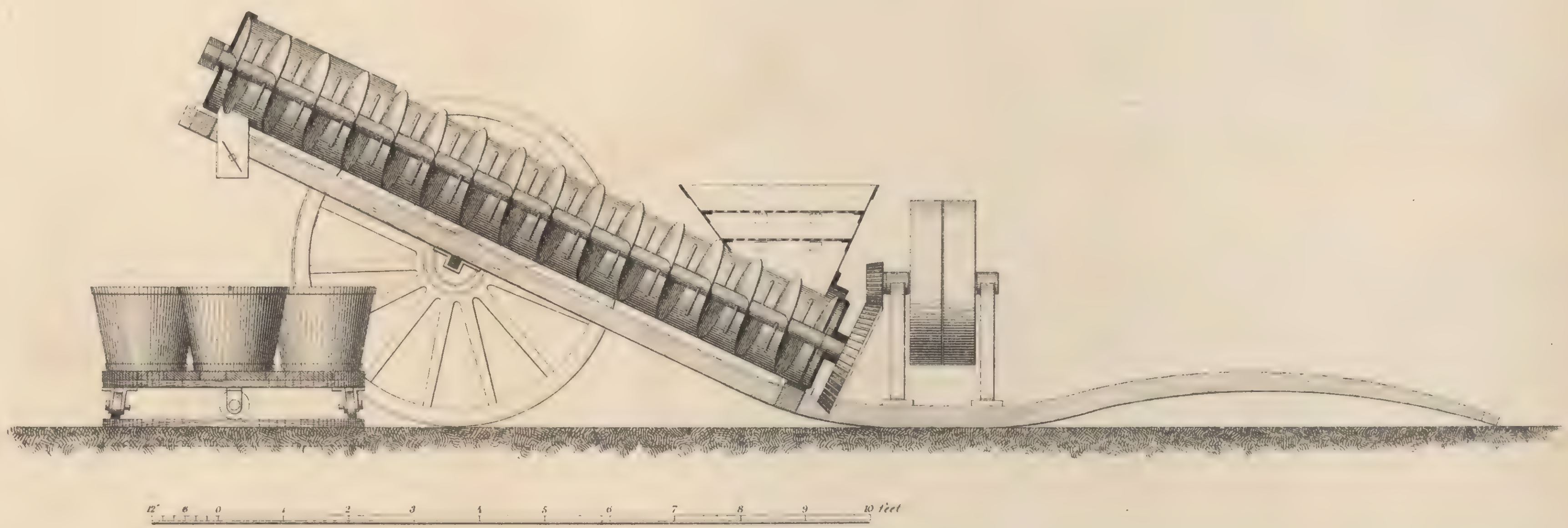
Pl. III.

THE GREYVELDINGER MORTAR MILL (MODIFIED)



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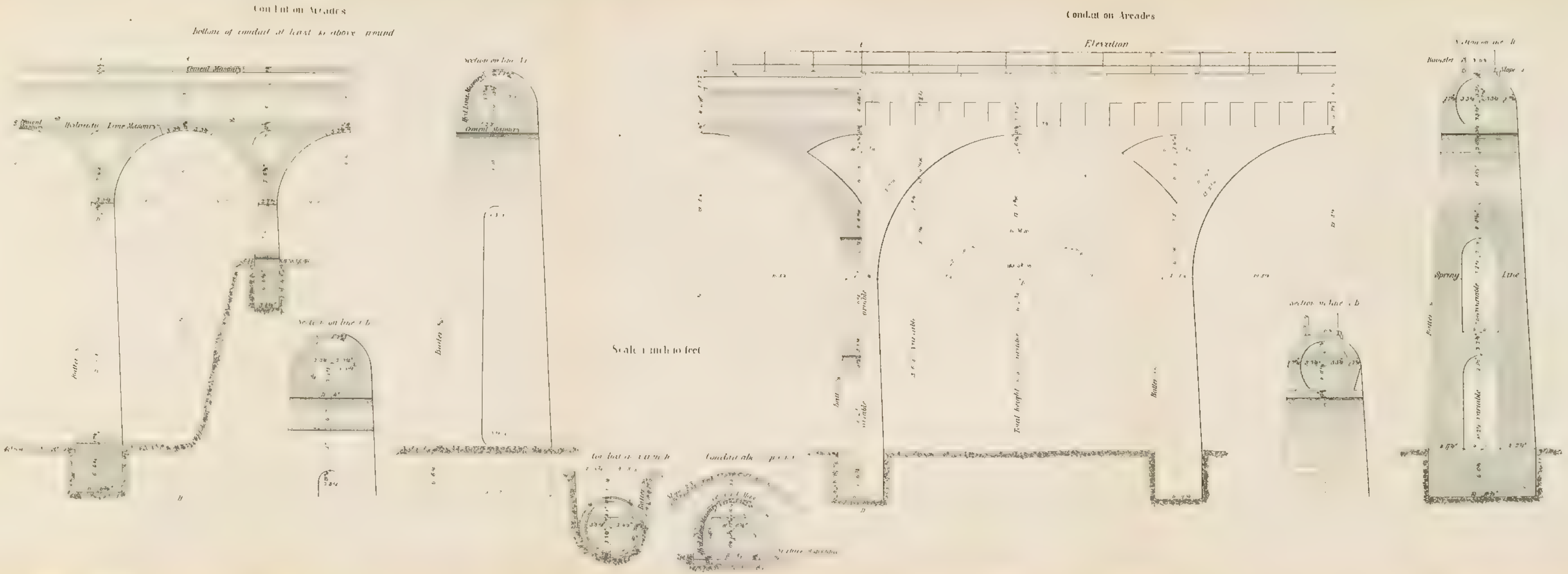
DETAILS OF THE VANNE AQUEDUCT. FRANCE.

Pl. IV



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THE VANNE AQUEDUCT, FRANCE.

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THE VANNE AQUEDUCT, FRANCE.

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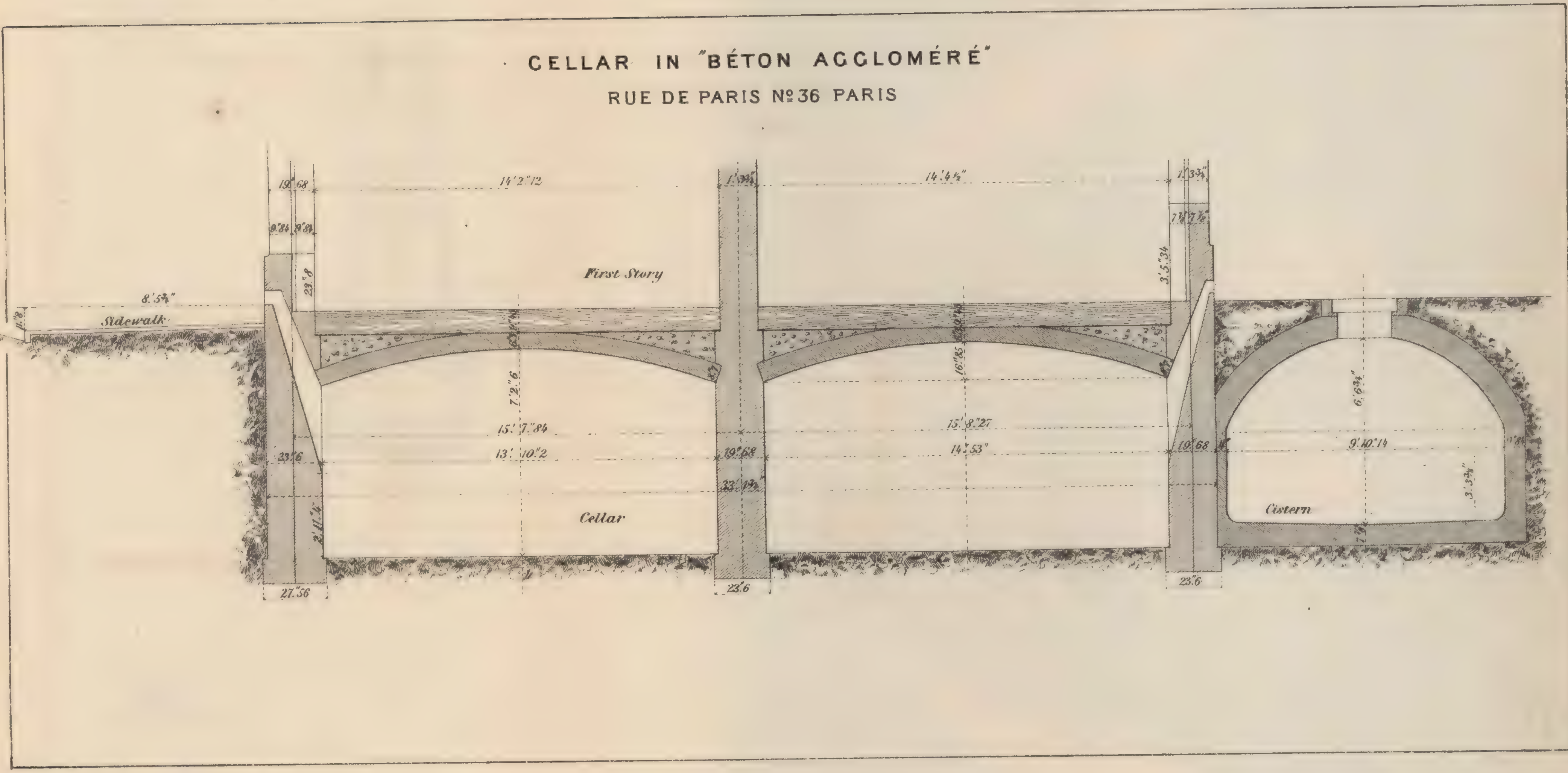
PI. VII.


CELLAR IN "BÉTON AGGLOMÉRÉ"
RUE DE PARIS No 36 PARIS
First Story
Sidewalk
Cellar
Cistern

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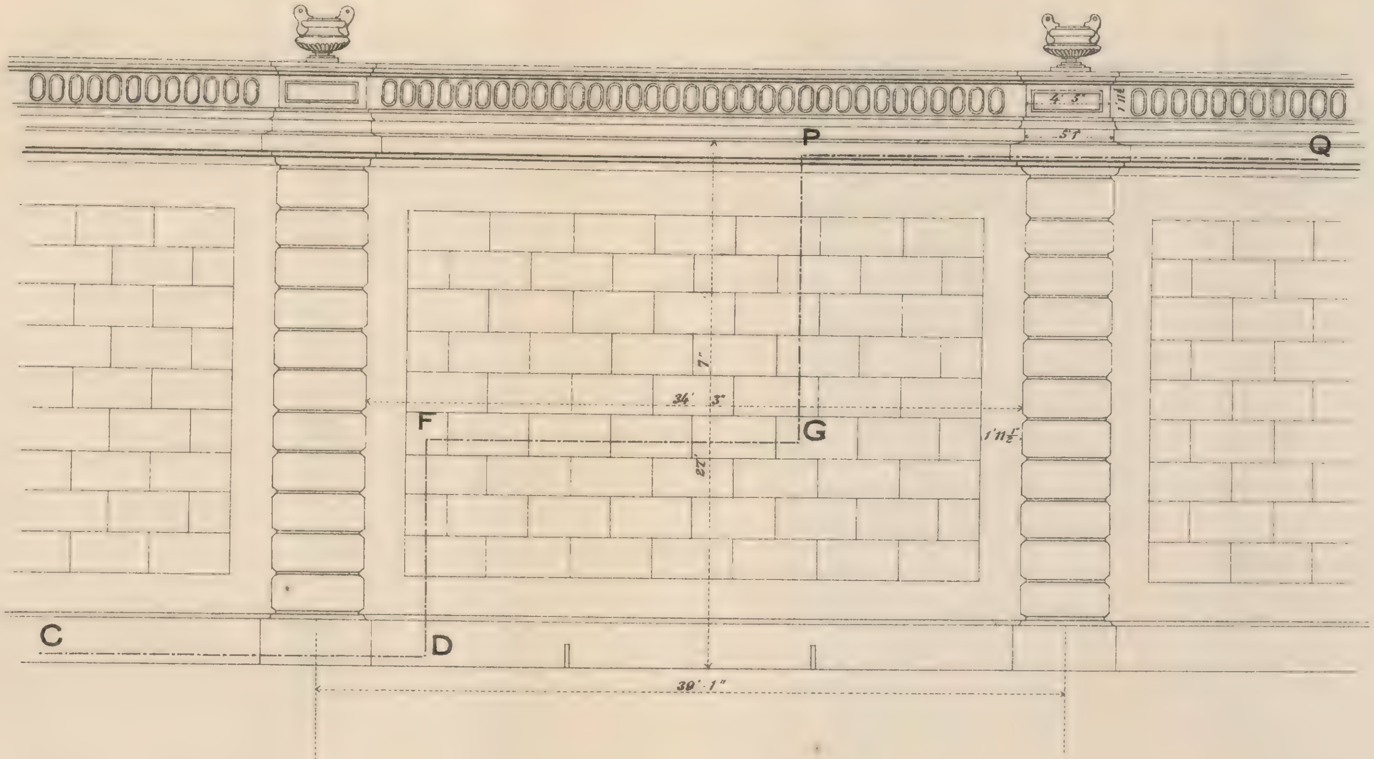
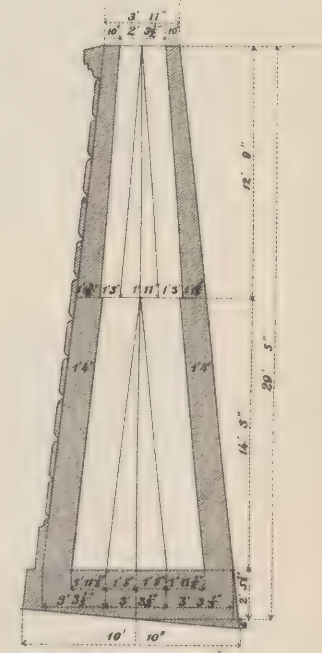
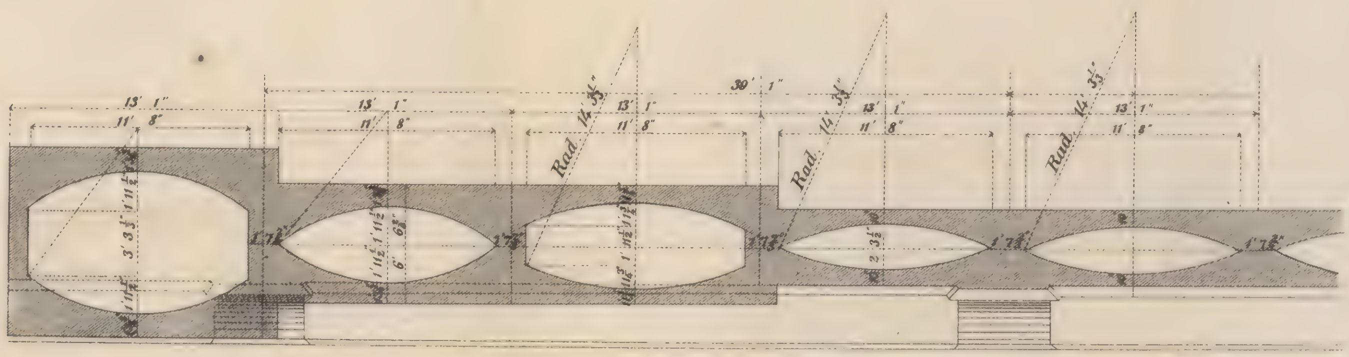
SUSTAINING WALL OF THE CEMETERY AT PASSY,

NEAR PARIS, FRANCE.

IN "BÉTON AGGLOMÉRÉ".







Section on line **C.D.F.G.P.Q.**

Scale : 1 inch = 10 feet.

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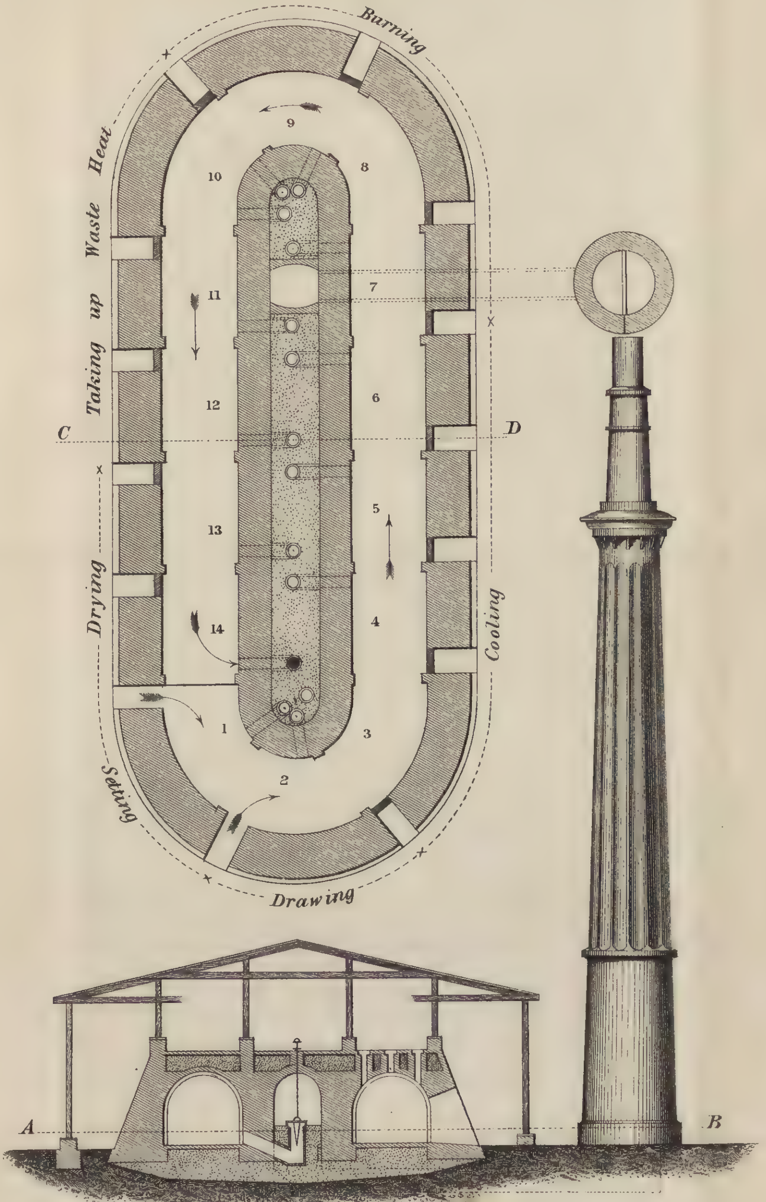
HOFFMANN'S ANNULAR KILN.

Section on line A.B.



Section on line C.D.

Scale 1" = 24 ft.

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